呉工業高等専門学校

研究報告

第13巻　第1号（通巻第20号）
昭和52年9月（1977）

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Christianity and Eastern Philosophy in *East of Eden*

（アメリカ文学） 下 村 登

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In the previous issues of the *MEMOIRS* (Vol. 9, No.1 & Vol. 12, No.1), I reported on "Mysticism in *To a God Unknown*" and "Social Goncern and Mysticism in *The Grapes of Wrath*," respectively. In the former thesis, in order to pursue the main theme of the novel, I studied the relationship between the two categories—Christianity and paganism—into which so many references and allusions to mysticism are classified. In the latter one, to clarify what makes the novel, as it were, immortal, I examined the correlation between social concern and mysticism.

In this paper, on the other hand, in order to grasp the purport of Steinbeck's unique evangelical message, I have investigated the correlation between Christian doctrine represented by both the Hamiltons and the Trasks and Eastern philosophy by Lee, the Chinese servant, as a series of my research of Steinbeck's mysticism.

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Introduction

"I am choosing to write this book to my sons. They are little boys now and they will never know what they came from through me, unless I tell them. It is not written for them to read now but when they are grown and the pains and joys have tousled them a little.... I want them to know how it was, I want to tell them directly, and perhaps by speaking directly to them I shall speak directly to other people.... They have no background in the world of literature, they don't know the great stories of the world as we do. And so I will tell them one of the greatest, perhaps the greatest story of all—the story of good and evil, of strength and weakness, of love and hate, of beauty and ugliness" (JS-PC, 1/29/51).[1] This is Steinbeck's remark on one of his starting days of writing this novel. He inststs that he is going to write this book for his sons, Tom and John,—for their future knowledge. He goes on to state, "I have written each book as an exercise, as practice for the one to come. And this is the one to come. There is nothing beyond this book—nothing follows it. It must contain all in the world I know and it must have everything in it of which I am capable—all styles, all techniques, all poetry—and it must have in it a great deal of laughter" (JS-PC, 2/12/51).[2] Later he goes so far as to call this novel "The Book" (JS-PC, 7/9/51).[3]

The above quoted remarks reveal his great expectation and confidence imposed upon the book. Contrary to his zeal, however, most critics are unfavorable to the book. For instance, Peter Lisca, who is his most understanding critic, criticizes *East of Eden* quite severely, saying, "To these faults of structure and theme must be added one other fault which, except for Steinbeck's first novel, had not been evident until *Burning Bright*—the failure of language,"[4] and "but it is certain that the new direction of *Burning Bright* and *East of Eden* had disastrous consequences for his art."[5] Peter Lisca apparently seeks to find the "agglutination of materials," and the book's "essential failure" in the history of its composition. By the former phrase he seems to mean that the novel unnaturally forces together the story of the fictional Trask family with "an accurate, factual account of Steinbeck's own maternal family, the Hamiltons."[6] He cites substantial evidences from the first draft of the novel and from the letters Steinbeck wrote in 1948 that the book was originally intended as a family history written for his own sons.[7] At some time, however, "as late as March of 1949" a change of plans took place: "Somewhere in the early stages of this family saga, however, Steinbeck introduced a fictional family, the Trasks, and he soon found himself at the mercy of his materials. The importance of the Trask family in the novel grew until the author realized that he had a far different book on his hands from what he had originally conceived, one which centered on the Trasks and not on the Hamiltons, Steinbeck's maternal family. By this time, however, the two families were inextricably entangled, and the author decided to keep them that way, but reduced the story of his own family to its vestigial elements and struck out all the special passages written to his sons."[8] All things considered, Peter Lisca seems to go so far as to brand this novel as a "total failure."[9] As well as many other critics including Peter Lisca, Prof. Hideo Inazawa, the distinguished Japanese Steinbeck critic, points out its structural flaw, saying that Steinbeck should have struck out the part of the Hamilton family and instead concentrated on Adam's grief which lasts for more than a decade after Cathy's departure.[10]

Expecting his critics' chorus of severe criticism, however, Steinbeck dares to insist: "It will also be said that I could well leave the Hamiltons out of the book because they do not contribute directly nor often to the Trask development. And I must be very willful about this, because this is not a story about the Trasks but about the whole Valley which I am using as a microcosm of the whole nation. It is not a romanza. I know I will have that war to fight" (JS-PC, 4/23/51).[11] Surely, as Lester Jay Marks puts it, "The Hamilton famly—Samuel, Liza, and their half dozen children of diverse personality—is Steinbeck's device for giving breadth and depth to the microcosmic adventures of Adam Trask and his two sons."[12] Marks compares the sections of the book involving the Hamiltons to the inter-chapters of *The Grapes of Wrath*—"either to reflect and generalize action that has occurred, or to signal action that is to come."[13] Notwithstanding Mark's enthusiastic advocacy, Steinbeck's attempts to impose an order on his diverse materials in no way prove so successful.

Therefore, we can neither call this novel "The Book" as Steinbeck insists, nor can we brand it as a "total failure"[14] as Peter Lisca seems to maintain. This is because we are greatly moved by his sincerity and skill of telling the unique evangelical message in spite of its structual flaw. Consequently, evaluating this novel as reaching a peak next to *The Grapes of Wrath,* let us examine it from the view-point suggested in the title of this paper.

As the title of the novel suggests, its theme centers on a modern version of the Cain and Abel story, told through the three generations of the Trask family. Steinbeck regards this story in Genesis as a true account of human conditons, especially when made clear in the God's words to Cain after rejecting his sacrifice. Steinbeck grounds his interpretation of the story on a new version of the Hebrew word *"timshel,"* which the King James version renders as "Thou shalt," and which the American Standard Bible renders as "Do thou." He suggests that the word is more meaningfully and truly rendered as "Thou mayest," for this gives man the dignity of free will. By uttering this word *"timshel"* the central figure Adam is finally saved through his inner struggles. It is Lee, the Chinese servant, that gives out the new version of the word and successfully guides Adam to his salvation of soul with might and main. A Chinese merchant with the same family name, Lee Chong, appears in *Cannery Row* (1945): "Lee Chong is more than a Chinese grocer. He must be. Perhaps he is evil balanced and held suspended by good—an Asiatic planet held to its orbit by the pull of Lao Tze and held away from Lao Tze by the centrifugality of abacus and cash register—Lee Chong suspended, spinning, whirling among groceries and ghosts. A hard man with a can of beans—a soft man with the bones of his grandfather."[15] Lee here in this novel is portrayed as a quite human and humorous man, while another Lee in *East of Eden* is at once a servant and a philosopher. He acts as Steinbeck's spokesman, but he is more than that. He is endowed with wisdom acquired through the long history of the race's once glorious culture and then tragedy and servitude. He seems to be a Confucian as most Chinese used to be, and at the same time a Taoist who secretly enjoys his unrestrained, free will, most unnoticed as a servant.

In this paper, I regard both the Hamiltons and the Trasks as belonging to the Christian world, as a "microcosm of the whole nation." Under the category of Christianity the history of the Hamiltons is rendered as the requiem for the family and that of the Trasks as the "C-A theme." Next, I will examine the Biblical background of the Cain and Abel story. And on the other hand, under the category of Eastern philosophy, I will examine the character of Lee, the Chinese servant, and of the four old Chinese gentlemen who study the Hebrew word *"timshel"* for over two years together with Lee. And then I will examine Confucianism, which used to be the race's basic moral rule, and Taoism, which is apparently contradictory to it. Lastly I will examine the correlation between Christianity represented by both the families and Eastern philosophy by Lee, thus finally coming to the analysis of Steinbeck's evangelical message and of how man, Cain's offspring, can be saved.

I. Christianity

1. History of the Hamiltons: Requiem for the Family

Steinbeck reveals a common coloring—some autobiographical elements—in some of his works, telling the readers about his own childhood. Especially in *East of Eden* the characteristic is conspicuous:

> I remember my childhood names for grasses and secret flowers. I remember where a toad may live and what time the birds awaken in the summer—and what trees and seasons smelled like—how people looked and walked and smelled even. The memory of odours is very rich.
>
> I remember that the Gabilan Mountains to the east of the valley were light gay mountains full of sun and loveliness and a kind of invitation, so that you wanted to climb into their warm foothills almost as you want to climb into the lap of a beloved mother. They were beckoning mountains with a brown grass love. The Santa Lucias stood up against the sky to the west and kept the valley from the open sea, and they were dark and brooding—unfriendly and dangerous. I always found in myself a dread of west and a love of east.[16]

Steinbeck goes on remembering one after another the old scenes of the Salinas Valley in each season, using the first person. Clearly this novel smacks of his autobiography. This is because this book was originally intended to be his family history told for his sons, as he insists.

Steinbeck's maternal grand-father, Samuel Hamilton, immigrated from Ireland together with his wife Liza about 1870 and settled in the east of King City, California. "Samuel had good looks and charm and gaiety. It is hard to imagine that any country girl refused him. He came to the Salinas Valley full-blown and hearty, full of inventions and energy. His eyes were very blue, and when he was tired one of them wandered outwards a little. He was a big man but delicate in a way. In the dusty business of ranching he seemed always immaculate. His hands were clever. He was a good blacksmith and carpenter and woodcarver, and he could improvise anything with bits of wood and metal. He was for ever inventing a new way of doing an old thing and doing it better and quicker, but he never in his whole life had any talent for making money. Other men who had the talent took Samuel's tricks and sold them and grew rich, but Samuel barely made wages all his life" (p. 6). He was handsome and had very clever hands. He built a house, barn and a blacksmith shop with his own hands. Soon he found that his large land was almost useless without water. He built a well-boring rig, and he bored wells for other people. He invented and built a threshing machine and moved through the valley in harvest time, threshing the grains for others. And in his shop he sharpened ploughs and mend-ed harrows and welded broken axles and shod horses. Men from all over the district brought him tools to mend. They all loved to hear him talk of the world and its thinking, of poetry and philosophy that were going on outside the valley. "He had a rich deep voice, good both in song and in speech, and while he had no brogue there was a rise and a lilt and a cadence to his talk that made it sound sweet in the ears of the taciturn farmers from the valley bottom" (p. 7). They liked his witty,comical stories. They called him "comical genius." He should have been very rich, but he had no gift for business. His customers, always pressed for money, promised payment after harvest, and then after Christmas, and then after—until at last they forgot it. He had no gift for reminding them, so the family stayed always poor. It was in such situations that Adam sent for Samuel to dig wells. But Liza persistently tried to dissuade him from going to Adam's, suspecting of the usual result. This time he would not listen to her : "'Mother,' Samuel cried, 'here's our chance to scratch our name in the First National Bank! Don't throw the weight of your tongue in the path of fortune. Please, Mother!'" (p. 157).

So eager to earn a considerable sum of money, he went out. In this way Samuel came to know Adam and Lee, the Chinese servant. After his second daughter Una' sudden death, he became remarkably old and weak. He died at the home of Steinbeck's mother Olive and was buried at the Salinas cemetery.

Before going away to Salinas, he had left his last remark to Lee: " 'Thou mayest rule over sin,' Lee. That's it. I do not believe all men are destroyed. I can name you a dozen who were not, and they are the ones that the world lives by. It is true of the spirit as it is true of battles—only the winners are remembered. Surely most men are destroyed, but there are others who like pillars of fire guide frightened men through the darkness. . . ." (p. 268). Samuel insisted that, though most men are destroyed, there are others who are not destroyed. And my further research will prove that Samuel himself is, undestroyed, one of the "others who like pillars of fire guide frightened men through the darkness."

Liza is also one of the "others." This fact can be proved by some examples. One of them is the case in which she helped Adam for the frightened Lee and Samuel immediately after Cathy's childbirth. "She had a dour Presbyterian mind and a code of morals that pinned down and beat the brains out of nearly everything that was pleasant to do" (p. 6). She believed in the Bible without questioning. Her faith was a "mountain" (p. 219). Though she as well as Samuel could be one of the "others" by her firm faith, she was "a very different kettle of fish" (p. 8), and "a tight hard little woman humourless as a chicken" (p. 6). "Her head was small and round and it held small round convictions. She had a button nose and a hard little set-back chin, a gripping jaw set on its course even though the angels of God argued against it" (p. 8). The following quotation shows the basic difference of character between the couple.

> Una's death struck Samuel like a silent earthquake. He said no brave and reassuring words, he simply sat alone and rocked himself. He felt that it was his neglect that had done it.
>
> And now his tissue, which had fought joyously against time, gave up a little. His young skin turned old, his clear eyes dulled, and a little stoop came to his great shoulders. Liza with her acceptance could take care of tragedy; she had no real hope this side of Heaven. But Samuel had put up a laughing wall against natural laws, and Una's death breached his battlements. He be-

came an old man. (p. 239)

She died at Olive's "with a pinched little smile on her mouth, and her cheekbones were shockingly high when the red was gone from them" (p. 424). She had given birth to four sons and five daughters. "A good part of her life was taken up with bearing and raising" (p. 35).

George, the eldest of the four sons, was "a tall handsome boy, gentle and sweet, who had from the first a kind of courtliness. Even as a little boy he was polite and what they used to call 'no trouble'" (p. 31). He inherited the neatness of his appearance from his father. He was "a sinless boy and grew to be a sinless man" (p. 31). In his middle age, he proved to have pernicious anaemia. It is considered possible that "his virtue lived on a lack of energy" (p. 31). In short, he was neither a useful son, nor a harmful one. Steinbeck does not tell about him any more than the following: "His other children (than the dead Una) were doing well. George was in the insurance business" (p. 239).

Will, the second son, had "little imagination but he had great energy. From childhood on he was a hard worker, if anyone would tell him what to work at, and once told he was indefatigable. He was a conservative, not only in politics but in everything. Ideas he found revolutionary, and he avoided them with suspicion and distaste. Will liked to live so that no one could find fault with him, and to do that he had to live as nearly like other people as possible" (p. 31). All his life he was lucky. "Certain individuals, not by any means always deserving, are truly beloved of the gods. Things come to them without their effort or planning. Will Hamilton was one of these. And the gifts he received were the ones he could appreciate. As a growing boy Will was lucky. Just as his father could not make money, Will could not help making it" (p. 32). At first he succeeded in the chicken business and then in the bicycle-and-tool business. In short he grew up to be a shrewd merchant without affinity to his father's imaginative, or his mother's religious nature. He became a prosperous automobile dealer and then one of the most influential business men in King City. In the course of time he sold an automobile to Adam. He also came to loan a considerable sum of money to Caleb, Adam's twin son, for bean investment. In the novel he is portrayed as very successful, but his end is not mentioned. In *Journal of a Novel* Steinbeck tells the truth: "Only Will can come back. What really happened to Will is so silly that I cannot use it. His wife died. He married his stenographer. She got him to retire to golf and travel and he died of boredom in six months. It's too pat. I couldn't think of using it"[17]

Tom, the third son, was "most like his father. He was born in fury and lived in lightning. Tom came headlong into life. He was a giant in joy and enthusiasm" (p. 33). He was a "dark-faced man; his skin, perhaps from sun, was a black red, as though some Norse or perhaps Vandal blood was perpetuated in him. His hair and beard and moustache were dark red too, and his eyes gleamed startlingly blue against his colouring. He was powerful, heavy of shoulders and arm, but his hips were slim. He could lift and run and hike and ride with anyone, but he had no sense of competition whatever. Will and George were gamblers and often tried to entice their brother into the joys and sorrows of venture" (p. 240). On the contrary, Tom was so sensitive as to write "secret poetry, and in those days it was only sensible to keep it secret. The poets were pale emasculates, and Western men held them in contempt. Poetry was a symptom of weakness, of degeneracy and decay" (p. 245). He was "as inventive as his father but he was bolder" (p. 33), and perhaps "it was his driving sexual need that made him remain a bachelor. It was a very moral family he was born into. It might be that his dreams and his longing, and his outlets, for that matter, made him feel unworthy, drove him sometimes whining into the hills. Tom was a nice mixture of savagery and gentleness"(p. 33). After his parents' departure to Salinas he stayed alone at the old Hamilton ranch together with the broken-hearted and frustrated Dessie. He was always tortured by his over-consciousness of himself and of good and evil (p. 357). He seems to have committed suicide, thinking that he had killed Dessie by mistake (p. 358).

Joseph, the fourth son, was "a kind of mooning boy, greatly beloved and protected by the whole family. He early discovered that a smiling helplessness was his best protection from work. His brothers were tough hard workers, all of them. It was easier to do Joe's work than to make him do it" (p. 34). He was also "physically lazy, and probably mentally lazy too. He day-dreamed out his life, and his mother loved him more than the others because she thought he was helpless. Actually he was the least helpless, because he got exactly what he wanted with a minimum of efforts. Joe was the darling of the family" (p. 34). He was to be sent to college because he was no good at anything else (p. 34). He had gone east and was engaged in a new job of advertising. Contrary to his parents' expectation, his "very faults were virtues in this field. He found that he could communicate his material day-dreaming—and, properly applied, that is all advertising is. Joe was a big man in a new field" (p. 239).

The romantic temperament of the four sons' father was reflected most conspicuously in Tom and least in Will. Of the four sons, only the two appear as minor heroes: Tom is portrayed as an innocent and pure young man suffering from his own over-consciousness of himself, but on the other hand Will as a shrewd merchant always trying to catch up with the fad of his days.

There were five daughters interspersed with the boys in the family.

Lizzie, the eldest daughter (Steinbeck guesses so because she was named after her mother), "early seemed to find a shame for her family. She married young and went away and thereafter was seen only at funerals. Lizzie had a capacity for hatred and bitterness unique among the Hamiltons. She had a son, and when he grew up and married a girl Lizzie didn't like she did not speak to him for many years" (p. 35). Never again does she appear in the novel.

Una, the second daughter (Steinbeck is not certain which is older, Lizzie or Una), was a "thoughtful, studious, dark girl" (p. 35). She was of all his daughters "Samuel's greatest joy. Even as a little girl she hungered for learning as a child does for cookies in the afternoon" (p. 238). About learning, the father and daughter had an implicit mutual understanding between them (p. 238). "Of all the children Una had the least humour. She met and married an intense dark man—a man whose fingers were stained with chemicals, mostly silver nitrate" (p. 238). He had been devoting his life to the development of color-film. The couple moved to somewhere on the border of Oregon. There she was killed by the accidental explosion in the laboratory and her body was shipped home (p. 238). George, Steinbeck's uncle, his eyes filled with tears, told Steinbeck about her miserable death many years later: "Una was not a beautiful girl like Mollie,...But she had the loveliest hands and feet....And Una had lovely skin too, translucent, even glowing. ...And then they brought her home. Her nails were broken to the quick and her fingers cracked and all worn out. And her poor, dear feet—...Her feet were broken and gravel-cut and briar-cut. Her dear feet had not worn shoes for a long time. And her skin was rough as rawhide" (p. 239). Her accidental death dealt Samuel a fatal blow and he suddenly became "an old man" (p. 239).

Dessie, the third daughter, was such a girl "whose laughter was so constant that everyone near her was glad to be there because it was more fun to be with Dessie than with anyone else" (p. 35). She was "not beautiful. Perhaps she wasn't even pretty, but she had the glow that makes men follow a woman in the hope of reflecting a little of it" (p. 341). She was running a dress-making shop, which was a "unique institution in Salinas. It was a woman's world" (p. 245). Her shop was once very prosperous. But soon afterwards she suffered from her lost love. Besides she was beaten by the growing popularity of ready-made clothes. Doubly frustrated, she retired to the old Hamilton house to live with Tom, because "Tom loved Dessie best" (p. 35) of all his family. She fell seriously ill at the abdomen, when Tom gave her a glass of pearly liquid of salt (p. 354). Overnight she suffered a severe pain and finally died. "Dessie's eyes were milky and crazy, like those of a maddened horse. Her mouth corners erupted thick bubbles and her face was on fire. Tom put his hand under the cover and felt muscles knotted like iron. And then her struggle stopped and her head fell back and the light glinted on her half-closed eyes" (p. 355). A week after Dessie's funeral, Tom seems to have committed suicide with a gun, pretending an accidental death for his mother's sake (p. 358).

In *Journal of a Novel* Steinbeck remarks about the episode of Dessie and Tom: "And in effect it is a kind of a dreadful story. It is the end of the Hamiltons in one sense and in one direction. In all of it you will find a kind of play-acting, like children being kings and queens. That has always seemed very sad to me and how much sadder if it is grown-up people playing at kings and queens. That's what this is—a travesty"[18] And then he confesses that for a while he thought he could better leave it out, but that he guessed he could not, because from the first it had been integrated with the story in his mind.[19]

Olive (Steinbeck's mother), the fourth daughter, became a primary school teacher at eighteen. She became a celebrity in the country, and was wooed and wedded with Earnest Steinbeck who was running a mill. She became Mrs. Steinbeck and bore three daughters and one son (Steinbeck). She was devoted to household affairs. She was a gentle and strict mother (p. 128). "Her theology was a curious mixture of Irish faries and an Old Testament Jehovah whom in her later life she confused with her father. Heaven was to her a nice home ranch inhabited by her dead relatives" (p. 128). Talking of her profession, in Steinbeck's novels appear some primary school teachers, such as Miss Martin, Miss Morgan in *The Pastures of Heaven*, and Elizabeth in *To a God Uuknown*. In these young teachers there seems to be reflected some of the mother's figure. On the other hand, Steinbeck never mentions his father (of the German lineage) in the novel, but in *Journal of a Novel* he writes: "My father was not an inventive man and he always said the Hamiltons were crazy. It was because he did not understand them. One is always crazy. Also the inventions of the Hamiltons did not make money. Money always removes the charge of craziness"[20] In the same book he mentions the difference of character between the parents.[21] His father was too realistic to be mentioned in the novel. Steinbeck seems to have been more strongly influenced by his maternal family than by his paternal one, for many of his maternal relatives lived in and around Salinas. Especially his grandmother lived long with him and died in his parents' home (p. 424).

Mollie, the fifth daughter, was "a little beauty with lovely blonde hair and violet eyes" (p. 35). She married William J. Martin and the couple went away to live in San Francisco (p. 219). She never appears again except on that memorable Thanksgiving Day (p. 247).

As I have already put it, Steinbeck seems to have been more strongly-influenced by his maternal family—of the Irish lineage. He was strongly conscious of his blood. The following quotations will prove the fact.

> The Irish do have a despairing quality of gaiety, but they have also a dour and brooding ghost that rides on their shoulders and peers in on their thoughts. Let them laugh too loudly, it sticks a long finger down their throats. They condemn themselves before they are charged, and this makes them defensive always. (p. 33)
>
> "My Tom is a hell-bent boy. Always takes more on his plate than he can eat. Always plants more than he can harvest. Pleasures too much, sorrows too much. Some people are like that. . . ."(p.121)
>
> "...They (the Irish) 're a dark people with a gift for suffering way past their deserving. It's said that without whisky to soak and soften the world, they'd kill themselves. But they tell jokes because it's expected of them." (p. 141)
>
> It was a *Weltschmerz*—which we used to call "Welshrats" —the world sadness that rises into the soul like a gas and spreads despair so that you probe for the offending event and can find none. (pp. 151—152)
>
> He (Una's husband Anderson) had great contempt, born of fear, for the Hamiltons, for they all half believed they had wings—and they got some bad falls that way. (p. 238)

On the poetic imagination of the Irish, Dr. Shotaro Oshima, the distinguished Japanese scholar, elaborates in his *English Literature and Poetic Imagination.* The Irish are said to be mostly the descendants of the Celtic races. The Celtic races were exiled all the way over the sea from the Continent to the British Isles, especially to Ireland. Since they settled there, they have been economically wretched and politically oppressed. Reacting to the cruel realities, they have come to be full of imagination. They often confuse their dream with the realities, being extremely prone to dreaming. In short, their literature is visionary rather than realistic: more subjective than objective. They are economically the defeated, and so they appear merry in appearance but actually are full of tears inside. They still have a gloomy aura around them in which sorrow and delight are unreasonably mingled. Irish literature is tinted with the primitive melancholy coming out of the emotion of the unfortunate races who were driven over the sea.[22] This consciousness no doubt underlies all of his works. Sometimes it appears as an unrestrained laughter like in *Tortilla Flat* or sometimes as a ponderous speculation like in *East of Eden.*

As I have mentioned in the Introduction, this novel was originally intended as the history of the Hamiltons to be told for his sons, but gradually its importance shifted to the Trask story. However, I acknowledge the Hamilton story as "giving breadth and depth to the microcosmic adventures of Adam Trask and his two sons," as Lester Jay Marks puts it. And as I have quoted from the *Journal,* the episode of Dessie and Tom is "the end of the Hamiltons in one sense and in one direction." Moreover, Lee, the Chinese servant, remarks in the novel: "When Samuel Hamilton died the world went out like a candle. I relighted it to see his lovely creations, and I saw his children tossed and torn and destroyed as though some revengefulness was at work. . . . " (p. 523). Thus, the Hamilton story is not just the history for his sons, but consequently the requiem for the family.

2. History of the Trasks: the C-A Theme

Steinbeck explains in the *Journal* the source of the name of the Trasks and the bearings of the family: "Next our grandfather and his sons and his daughters and his wife and the land they took up near King City and how they lived, and some attempt to give them a quality of their background. And finally I want to menton the neighbors. I do not have the name yet. I think it might be Canable. No, that is a double or rather a triple meaning I don't want. The name is so important that I want to think about it. I remember a friend of my father's—a whaling master named Captain Trask. I have always loved the name. It meant great romance to me."[23] He goes on to express his opinion about the fictitious figures: "And further, since these people are essentially symbol people, I must make them doubly understandable as people apart from their symbols. A symbol is usually a kind of part of an equation—it is one part or facet chosen to illuminate as well as to illustrate the whole. The symbol is never the whole. It is a kind of psychological sign language. But in this book, which I want to have a semblance of real experience both visual and emotional and finally intellectual, I want to clothe my symbol people in the trappings of experience so that the symbol is discernible but not overwhelming."[24] The Trasks are meant to be the neighbors of the Hamiltons and symbol people unlike the Hamiltons, who lived their actual life. The above seems to show that Steinbeck tried to make the combination of the factual Hamiltons with the fictitious Trasks represent the whole valley "as a microcosm of the whole nation."[25] This is suggested by the following remark in the novel: "While many people came to the Salinas Valley penniless, there were others who, having sold out somewhere else, arrived with money to start a new life. These usually bought land, but good land, ...Such a man was Adam Trask" (p. 9). If the Trasks are of the latter type, then the Hamiltons must be of the former one.

Moreover, following what Steinbeck called "my C-A theme,"[26] the Trasks and their relatives are classified into two groups, the Cain and the Abel characters: Cyrus, Charles, Cathy and Caleb, and Alice, Mr. and Mrs. Ames, Aron and Abra (Bacon).

First let us examine the C-theme of the "C-A theme."

Cyrus, Adam's father, was "something of a devil—had always been wild—drove a two-wheeled cart too fast, and managed to make his wooden leg seem jaunty and desirable. He had enjoyed his military career, what there was of it. Being wild by nature, he had liked his brief period of training and the drinking and gambling and whoring that went with it. Then he marched south with a group of replacements, and he enjoyed that too—seeing the country and, stealing chickens and chasing rebel girls up into the haystacks. The grey, despairing weariness of protracted manœuvres and combat did not touch him. The first time he saw the enemy was at eight o'clock one spring morning, and at eight-thirty he was hit in the right leg by a heavy slug that mashed and splintered the bones beyond repair. Even then he was lucky, for the rebels retreated and the field surgeons moved up immediately. Cyrus Trask did have his five minutes of horror while they cut the shreds away and sawed the bone off square and burned the open flesh" (p. 10).

While he was still in hospital, he contracted a particularly malignant disease from a negro girl. Soon after he was discharged from the army, Mrs. Trask was infected with his gonorrhea. This caused Mrs. Trask to commit suicide in the water, leaving the baby Adam behind. A month had scarcely passed when he wooed and wedded a 17-year-old plain girl, Alice, a daughter of one of his heighboring farmers. Soon Alice bore a boy, Adam's half-brother. Cyrus launched on a new career as an old soldier: "While he continued to operate his farm as such farms were operated in the neighbourhood, he entered on a new career—that of the old soldier. And that energy which had made him wild now made him thoughtful. No one now outside the War Department knew the quality and duration of his service. His wooden leg was at once a certificate of proof of his soldiering and a guarantee that he wouldn't ever have to do it again. Timidly he began to tell Alice about his campaigns, but as his technique grew so did his battles. At the very first he knew he was lying, but it was not long before he was equally sure that every one of his stories was true. Before he had entered the service he had not been much interested in warfare; now he bought every book about war, read every report, subscribed to the New York papers, studied maps. His knowledge of geography had been shaky and his information about the fighting non-existent; now he became an authority. He knew not only the battles, movements, campaigns, but also the units involved, down to the regiments, their colonels, and where they originated. And from telling he became convinced that he had been there" (pp. 12—13). "Quite early he began to write letters and then articles about the conduct of the war, and his conclusions were intelligent and convincing"(p. 13). "His articles in various magazines attracted attention. His letters to the War Department, printed simultaneously in the newspapers, began to have a sharp effect in decisions on the army" (p. 13). "And such a voice in military matters Cyrus Trask became. It came about that he was consulted in matters of army organisation, in officer relationships, in personnel and equipment. His expertness was apparent to everyone who heard him. He had a genius for the military. More than that, he was one of those responsible for the organisation of the G.A.R. as a cohesive and potent force in the national life. After several unpaid offices in that organisation, he took a paid secretaryship which he kept for the rest of his life. He travelled from one end of the country to the other, attending conventions, meetings, and encampments. So much for his public life" (p. 14).

He managed his private household in an army way. Alice, taciturn, preferred it that way. He also disciplined and trained his children as little soldiers. "It was the little boys who really caught it. Cyrus had decided that even though the army was not perfect, it was still the only honourable profession for a man. He mourned the fact that he could not be a permanent soldier because of his wooden leg, but he could not imagine any career for his sons except the army. He felt a man should learn soldiering from the ranks, as he had. Then he would know what it was about from experience, not from charts and textbooks. He taught them the manual of arms when they could barely walk. By the time they were in grade school, close-order drill was as natural as breathing and as hateful as hell. He kept them hard with exercises, beating out the rhythm with a stick on his wooden leg. He made them walk for miles, carrying knapsacks loaded with stones to make their shoulders strong. He worked constantly on their marksmanship in the wood-lot behind the house" (pp. 14—15). Following his conviction, he sent the convalescent Adam to the army, where Adam served for ten years. When he died, he bequeathed a tremendous sum of money equally divided to Adam and Charles. Later, when Adam examined the scraps of old newspapers, he believed that Cyrus had stolen the money from the G.A.R. Adam called his father Cyrus "thief" (p. 507). In short Cyrus plays two roles: the father of the brothers and Yahweh as the gift-reciever (p. 24).

Charles, Adam's half-brother, only a little over a year younger than Adam, "grew up with his father's assertiveness. Charles was a natural athlete, with instinctive timing and coordination and the competitor's will to win over others, which makes for success in the world.

Young Charles won all contests with Adam whether they involved skill, or strength, or quick intelligence, and won them so easily that quite early he lost interest and had to find his competition among other children. Thus it came about that a kind of affection grew between the two boys, but it was more like an association between brother and sister than between brothers. Charles fought any boy who challenged or slurred Adam and usually won. He protected Adam from his father's harshness with lies and even with blame-taking. Charles felt for his brother the affection one has for helpless things, for blind puppies and new babies" (pp. 15—16). Once, a scene similar to the fratricide in the Cain and Abel story took place: "'Look at his birthday!' Charles shouted. 'I took six bits and I bought him a knife made in Germany —three blades and a corkscrew, pearl-handled. Where's that knife?...What did you do on his birthday? You think I didn't see? Did you spend six bits or even four bits. You brought him a mongrel pup you had picked up in the wood-lot. You laughed like a fool and said it would make a good bird dog. That dog sleeps in his room. He plays with it while he's reading. He's got it all trained. And where's the knife? 'Thanks,' he said, just 'Thanks'" (p. 24). Charles became furious with rage against Adam because of the father's partial love. He knocked Adam down, and tried to kill him with a hatchet. Adam narrowly escaped from the danger. Later, when Charles was working at the farm, he accidentally suffered a tatoo-like scar on the forehead like Cain's. After Adam's long wandering across the states, the brothers lived rather friendlily on the Trask farm. On the first night of Adam's marriage with Cathy, Charles was tempted by Cathy and he impregnated her. Thus, he became the real father of Caleb and Aron. He died at the old Trask farm and bequeathed his fortune equally divided to Adam and Cathy (p. 325).

Steinbeck believes that "there are monsters born in the world to human parents....And just as there are physical monsters, can there not be mental or psychic monsters born? The face and body may be perfect, but if a twisted gene or malformed egg can produce physical monsters, may not the same process produce a malformed soul?

Monsters are variations from the accepted normal to a greater or a less degree. ...It is my belief that Cathy Ames was born with the tendencies, or lack of them, which drove and forced her all of her life. Some balance wheel was misweighted, some gear out of ratio. She was not like other people, never was from birth. And just as a cripple may learn to utilise his lack so that he becomes more effective in a limited field than the uncrippled, so did Cathy, using her difference, make a painful and bewildering stir in her world" (p. 61).

Cathy's face reveals the image of a snake: "As though nature concealed a trap, Cathy had from the first a face of innocence. Her hair was gold and lovely; wide-set hazel eyes with upper lids that drooped made her look mysteriously sleepy. Her nose was delicate and thin, and her cheekbones high and wide, sweeping down to a small chin so that her face was heart-shaped. Her mouth was well shaped and well lipped but abnormally small—what used to be called a rosebud. Her ears were very little, without lobes, and they pressed so close to her head that even with her hair combed up they made no silhouette. They were thin flaps sealed against her head" (p. 62). "Her wide-set eyes communicated nothing" (p. 148). "The eyes were flat and the mouth with its small up-curve at the corners was carven" (p. 149). "She doesn't want the light. It hurts her eyes" (p. 164). Besides, she had a scar which "looked like a huge thumb-print" (p. 137) on the forehead like Cain did.

She always had a "child's figure even after she was grown, slender, delicate arms and hands—tiny hands" (p. 62). She was a "liar, but she did not lie the way most children do. Hers was no day-dream lying, ...Cathy's lies were never innocent" (p. 63). "At ten Cathy knew something of the power of the sex impulse and began coldly to experiment with it" (p. 64). At sixteen she tried to go away from her parents, but soon was caught, and severely whipped by her father (p. 72). Deceiving her parents by pretending to be a good girl, she brutally killed them by setting fire to their house (p. 75). She ran away, taking what money her parents had from the bank and the safe in the father's tannery. She became a kept woman of a whoremaster, Edwards (p. 80). When she was found to have swindled much money from him, she was badly hit and hurt almost to death (p. 85). She was narrowly saved by crawling up to the steps of the Trasks. Adam was so fascinated by her that he wooed and wedded her before she was completely well. On the first night of their marriage, she purposely gave to Adam a dose of her sleeping medicine and while he was sleeping, she entered Charles' bed (p. 108). She became pregnant and she bore twin-brothers, who were later named Caleb and Aron. She had scarcely recovered when she went away, deserting the newborn babies (p. 175). She went to Fay's whore-house in Salinas, and later secretly killed Fay by poisoning her. She took Fay's place (p. 218). She suffered arthritis (p. 411). She began to go to church (p. 423). But finally disappointed, she committed suicide and bequeathed her dirty money to the angel-like Aron (p. 481). Thus she seems to have three roles: Eve (Adam's wife), the snake (her snaky face and character), and Cain (her scar on the forehead).

Cal (Caleb) "looked more like Adam. His hair was dark brown. He was bigger than his brother, bigger of bone, heavier in the shoulder, and his jaw had the square sternness of Adam's jaw. Cal's eyes were brown and watchful, and sometimes they sparkled as though they were black. But Cal's hands were very small for the size of the rest of him. The fingers were short and slender, the nails delicate. Cal protected his hands. There were few things that could make him cry, but a cut finger was one of them. He never ventured with his hands, never touched an insect or carried a snake about. And in a fight he picked up a rock or a stick to fight with (p. 293). The following quotation well pictures Cal's character: "Cal's eyes stayed on her (Abra). She tried to stare him down. She was an expert at staring down, but Cal did not look away. At very first he had felt a shyness, but that was gone now, and the sense of triumph at destroying Abra's control made him laugh. He knew she preferred his brother, but that was nothing new to him. Nearly everyone preferred Aron with his golden hair and the openness that allowed his affection to plunge like a puppy. Cal's emotions hid deep in him and peered out, ready to retreat or attack. He was starting to punish Abra for liking his brother, and this was nothing new either. He had done it since he first discovered he could. And secret punishment had grown to be almost a creative thing with him" (p. 304).

The difference in character between the two boys, Cal and Aron, can best be described in this way: "If Aron should come upon an ant-hill in a little clearing in the brush, he would lie on his stomach and watch the complications of ant life—he would see some of them bringing food in the ant roads and others carrying the white eggs. He would see how two members of the hill on meeting put their antennæ together and talked. For hours he would lie absorbed in the economy of the ground.

If, on the other hand, Cal came upon the same ant-hill, he would kick it to pieces and watch while the frantic ants took care of their disaster. Aron was content to be part of his world, but Cal must change it" (p. 293). "From his first memory Cal had craved warmth and affection, just as everyone does" (p. 384). He struggled in his mind and prayed to God: "Dear Lord," he said, "let me be like Aron. Don't make me mean. I don't want to be. If you will let everybody like me, why, I'll give you anything in the world, and if I haven't got it, why, I'll go for to get it. I don't want to be mean. I don't want to be lonely. For Jesus' sake, Amen" (p. 332).

Later, when he grew up to be a young man, he came to guess from rumors that his mother Cathy was still alive and that she was running the most depraved whore-house. He became sure of it through Rabbit's careless remark (p. 386). He went to Cathy's whore-house and there he witnessed the "circus." After seeing his mother, he felt a passionate love for his father and wanted to comfort him (p. 390). He oten followed her secretly to her house and finally saw what she really was:

> Cal spoke happily, "I'm going," he said. "I'm going now. It's all right. What Lee said was true."
> "What did Lee say?"
> Cal said, "I was afraid I had you in me."
> "You have," said Kate.
> "No, I haven't. I'm my own. I don't have to be you."
> "How do you know that?" she demanded.
> "I just know. It came to me whole. If I'm mean, it's my own mean."
> "This Chinaman has really fed you some pap. What are you looking at me like that for?"
> Cal said, "I don't think the light hurts your eyes. I think you're afraid."
> "Get out!" she cried. "Go on, get out!"
> "I'm going." He had his hand on the door-knob. "I don't hate you," he said. "But I'm glad you're afraid." (p. 404)

In order to make up for his father's loss from the lettuce investment, Cal bought futures on beans and thereby made much money totaling $ 15,000. He wanted to give it to his father as a present on Thanksgiving Day. When Adam saw the money, he took a long time to answer: "'I send boys out,' he said. 'I sign my name and they go out. And some will die and some will lie helpless without arms and legs. Not one will come back untorn. Son, do you think I could make a profit on that?... No. I won't want it ever. I would have been happy if you could have given me—well, what your brother has—pride in the thing he's doing, gladness inhis progress. Money, even clean money, doesn't stack up with that.' His eyes widened a little and he said, 'Have I made you angry, son? Don't be angry. If you want to give me a present—give me a good life. That would be something I could value'" (p. 472). As a retort to Adam's rejection of his love, Cal invited Aron to Cathy's whore-house. Aron, completely discouraged by the ugly realities, volunteered in the army, and was killed in a battle at the Western front. Seriously shocked by the news, Adam lay nearly unconscious from a stroke. Cal confessed his sin and begged Adam's forgiveness in vain (p. 519).

Next let us examine the A-theme.

Alice was the second wife of the brutal father of Adam, Cyrus. She had "a number of admirable qualities. She was a deep scrubber and a corner-cleaner in the house. She was not very pretty, so there was no need to watch her. Her eyes were pale, her complexion sallow, and her teeth crooked, but she was extremely healthy and never complained during her pregnancy. Whether she liked children or not no one ever knew. She was not asked, and she never said anything unless she was asked. From Cyrus' point of view this was possibly the greatest of her virtues. She never offered any opinion or statement, and when a man was talking she gave a vague impression of listening while she went about doing the housework. The youth, inexperience, and taciturnity of Alice Trask all turned out to be assets for Cyrus" (p. 12). She bore Adam's half-brother, Charles. She "treated the boys equally, washed them and fed them, and left everything else to their father,..." (p. 16). Adam "ached towards her with a longing that was passionate and hot" (p. 17). He vaguely longed for what he had not received from his mother while he was a baby (p. 17). When he was badly hurt by Charles, she kindly nursed him, saying, "He (Charles) is a strange boy. You have to know him—all rough shell, all anger until you know" (p. 27). She died choking from her consumption while Adam was away in the army (p. 29).

Adam Trask was born "on a farm on the outskirts of a little town which was not far from a big town in Connecticut. He was an only son, and he was born six months after his father was mustered into a Connecticut regiment in 1862. Adam's mother ran the farm, bore Adam, and still had time to embrace a primitive theosophy. ...He (Cyrus) came home six weeks after Adam was born. His right leg was off at the knee. He stumped in on a crude wooden leg he himself had carved out of beechwood. And already it was splitting" (p. 10). "Adam found his father out. It wasn't that his father changed, but that some new quality came to Adam. He had always hated the discipline, as every normal animal does, but it was just and true and inevitable as measles, not to be denied or cursed, only to be hated. And then —it was very fast, almost a click in the brain—Adam knew that, for him at least, his father's methods had no reference to anything in the world but his father. The techniques and training were not designed for the boys at all but only to make Cyrus a great man. And the same click in the brain told Adam that his father was not a great man, that he was, indeed, a very strong-willed and concentrated little man wearing a huge busby. Who knows what causes this—a look in the eye, a lie found out, a moment of hesitation?—then god comes crashing down in a child's brain.

Young Adam was always an obedient child. Something in him shrank from violence, from contention, from the silent shrieking tensions that can rip at a house. He contributed to the quiet he wished for by offering no violence, no contention and to do this he had to retire into secretness, since there is some violence in everyone. He covered his life with a veil of vagueness, while behind his quiet eyes a rich full life went on. This did not protect him from assault but it allowed him an immunity" (p. 15).

Towards Alice, Adam "concealed a feeling that was akin to a warm shame. She was not his mother—that he knew because he had been told many times. Not from things said but from the tone in which other things were said, he knew that he had once had a mother and that she had done some shameful thing, such as forgetting the chickens or missing the target on the range in the wood-lot. And as a result of her fault she was not here. Adam thought sometimes that if he could only find out what sin it was she had committed, why, he would sin it too—and not be here" (p. 16). "And he ached towards her with a longing that was passionate and hot. He did not know what it was about, but all the long lack of holding, of rocking, of caressing, the hunger for breast and nipple, and the softness of a lap, and the voice-tone of love and compassion, and the sweet feeling of anxiety—all these were in his passion, and he did not know it because he did not know that such things existed, so how could he miss them" (p. 17). In the fight similar to the fratricidal one in the Cain-Abel story, Adam was nearly killed by his half brother, Charles. Still lying in bed, Adam was half-compulsorily enlisted in the cavalry by his father. (p. 28). In the cavalry the "emotion of non-violence was building in him until it became a prejudice like any other thought-stultifying prejudice. To inflict any hurt on any thing for any purpose became inimical to him. He became obsessed with this emtion, for such it surely was, until it blotted out any possible thinking in its area." (p. 29). Charles often wrote to him, eagerly asking him to come back to the Trask farm after his five years' service, but he remained another five years there. After that he wandered over almost all the states for several years. Finally, when he came back to Charles, he knew that his father Cyrus had already died, bequeathing a tremendous sum of money. Charles said he had loved his father, but Adam said, "I wasn't sure until now, . . . I was all mixed up with how I was supposed to feel. No, I did not love him" (p. 59). Anyway, Adam felt released and free (p. 59).

One evening, Cathy, the monster woman, who had been seriously wounded by Edwards, crawled up to the steps of the brothers' house. While Adam attended on her, suddenly "he knew joy and sorrow felted into one fabric. Courage and fear were one thing too. He found that he had started to hum a droning little tune. He turned, walked through the kitchen, and stood in the doorway, looking at Cathy. She smiled weakly at him, and he thought, What a child! What a helpless child! and a surge of love filled him" (p. 103). Adam loved Cathy so much that he married her before she recovered completely. However, Charles, suspicious of her, protested, "Won't you get rid of her? Please, Adam. Throw her out. She'll tear you to pieces. She'll destroy you, Adam, she'll destroy you!" (p. 106). On the same evening, Cathy slept with Charles and became pregnant. "Whatever Cathy may have been, she set off the glory in Adam. His spirit rose flying and released him from fear and bitterness and rancid memories. The glory lights up the world and changes it the way a star-shell changes a battle-ground. Perhaps Adam did not see Cathy at all, so lighted was she by his eyes. Burned in his mind was an image of beauty and tenderness, a sweet and holy girl, precious beyond thinking, clean and loving, and that image was Cathy to her husband, and nothing Cathy did or said could warp Adam's Cathy" (p. 112).

Thus, Adam moved to the Salinas Valley with the unwilling Cathy and settled in the east of King City. He proudly said to Samuel Hamilton, who came to the new Trask farm to dig wells for him: "Look, Samuel, I mean to make a garden of my land. Remember my name is Adam. So far I've had no Eden, let alone been driven out" (p. 145).

Adam had purchased a vast acreage of fertile land on the Salinas River with the tremendous bequeathed fund. He planned to build his own "Garden of Eden," deserving his name. He had employed a Chinese servant. Later Cathy bore twin brothers. Before she recovered enough from her child-birth, she deserted Adam and the new-born babies. "On the Trask place Adam drew into himself. The unfinished Sanchez house lay open to wind and rain, and the new floorboards buckled and warped with moisture. The laid-out vegetable gardens rioted with weeds.

Adam seemed clothed in a viscosity that slowed his movements and held his thoughts down. He saw the world through grey water. Now and then his mind fought its way upward, and when the light broke in it brought him only a sickness of the mind, and he retired into the greyness again. He was aware of the twins because he heard them cry and laugh, but he felt only a thin distaste for them. To Adam they were symbols of his loss" (p. 218). Lee, the Chinese servant, took care of the babies. Adam was so shocked that he left the babies unnamed for over a year. Thanks to Samuel's and Lee's kind suggestions, however, Adam was finally saved by the word "*timshel*" after suffering from many various distresses (p. 525).

Cathy's father, Mr. William Ames, was running a tannery. He was a "covert man. He rarely told the thoughts in his mind. He wouldn't have dared so far to expose himself to the gaze of his neighbours. He kept the little flame of suspicion to himself. It was better if he didn't know anything, safer, wiser, and much more comfortable. As for Cathy's mother, she was so bound and twisted in a cocoon of gauzy half-lies, warped truth, suggestions, all planted by Cathy, that she would not have known a true thing if it had come to her" (p. 67). Later, Cathy criticized her parents: "When I was a little girl I knew what stupid lying fools they were—my own mother and father pretending goodness. And they weren't good. I knew them. ..." (p. 280). Finally, Mr. and Mrs. Ames were mercilessly killed in the fire by their own daughter Cathy (p. 75).

Aron grew up to be a handsome boy. His eyes were "very wide and he had a beautiful soft mouth. The width between his blue eyes gave him an expression of angelic innocence. His hair was fine and golden. The sun seemed to light up the top of his head.

He was puzzled—but he was often puzzled. He knew his brother was getting at something, but he didn't know what. Cal was an enigma to him. He could not follow the reasoning of his brother, and he was always surprised at the tangents it took" (p. 293). "Aron drew love from every side. He seemed shy and delicate. His pink-and-white skin, golden hair, and wide-set blue eyes caught attention. In the school-yard his very prettiness caused some difficulty until it was discovered by his testers that Aron was a dogged, steady, and completely fearless fighter, particularly when he was crying. Word got around, and the natural punishers of new boys learned to let him alone. Aron did not attempt to hide his disposition. It was concealed by being the opposite of his appearance. He was unchanging once a course was set. He had few facets and very little versatility. His body was as insensitive to pain as was his mind to subtleties.

Cal knew his brother and could handle him by keeping him off balance, but this only worked up to a certain point. Cal had learned when to sidestep, when to run away. Change of direction confused Aron, but that was the only thing that confused him. He set his path and followed it and he did not see nor was he interested in anything beside his path. His emotions were few and heavy. All of him was hidden by his angelic face, and for this he had no more concern or responsibility than has a fawn for the dappling spots of its young hide" (p. 366).

Aron first met the pretty little girl Abra wearing a sunbonnet when he was eleven years old. Both began to love each other (p. 303). As they grew to be youths, they dreamed of getting married. Later, when Cal came to know the truth about his mother, he loved his father better and felt an urge to protect him. On the other hand, Aron was caught "in the roil of change too, but his impulses were more sluggish than Cal's. His body did not scream at him so shrilly. His passion took a religious direction. He decided on the ministry for his future. ...Aron's religion inevitably took a sexual turn. He spoke to Abra of the necessity for abstinence and decided that he would live a life of celibacy. . . . Cal watched his brother triumph over sins he had never committed" (pp. 390, 391). Abra wanted to marry Aron and to bear his children, but now she could just hope this phase would pass as soon as possible. Aron was loved by Reverend Rolf at the Episcopal church. One day he was told that a whore-house mistress (Cathy) was coming to evening service. At high school Aron skipped a year due to his good grades and entered Stanford University. As soon as Aron knew the truth about his mother, he, disappointed, enlisted in the army and was killed in a battle at the Western front. (p. 517).

Abra, the pretty little daughter of Mr. and Mrs. Bacon, was first seen by the twin brothers when returning from rabbit hunting. The Bacons also had just entered the Adam house to look for shelter from a sudden shower. "Beside the woman sat a girl, a little younger maybe than the twins, but not much. She wore a blue-checked sun-bonnet with lace around the front. Her dress was flowery, and a little apron with pockets was tied around her middle. Her skirt was turned back, showing a petticoat of red knitted yarn with tatting around the edge. The boys could not see her face because of the sunbonnet, but her hands were folded in her lap, and it was easy to see the little gold seal ring she wore on her third finger" (p. 297). Mr. Bacon addressed the boys, "My daughter's name is Abra, boys. Isn't that a funny name?" And then he said to Adam, turning to him, "'Abra was ready ere I called her name; And though I called another, Abra came.' Matthew Prior. I won't say I hadn't wanted a son—but Abra's such a comfort. Look up, dear." (p. 298). Mr. Bacon's remark betrays his disappointment at her birth and his dispassionate mood of naming her. Her name "Abra" itself reveals his insincerity. Later, she made a promise to marry Aron. They played house, curtained by the branches of a willow-tree (p. 367). But Aron's devotion to religion took a sexual turn. "He spoke to Abra of the necessity for abstinence and decided that he would live a life of celibacy. Abra in her wisdom agreed with him, feeling and hoping that this phase would pass. ...She had never been jealous before, but now she began to find in herself an instinctive and perhaps justified hatred of the Reverend Mr. Rolf" (p. 391). After Aron went away to college, Abra really began to know his family (p. 427). "She found that she trusted Adam more, and loved Lee more, than her own father. ...Abra was a straight, strong, fine-breasted woman, developed and ready and waiting to take her sacrament—but waiting. She took to going to the Trask house after school, sitting with Lee, reading him part of Aron's daily letter" (pp. 427, 428). Cal told Abra that he had vengefully invited Aron to Cathy's. Abra said, "I didn't love Aron any more." "Why not," Cal asked. She replied, "I've tried to figure it out. When we were children we lived in a story that we made up. But when I grew up the story wasn't enough. I had to have something else, because the story wasn't true any more. ... Aron didn't grow up. Maybe he never will. He wanted the story and he wanted it to come out his way" (p. 503). Abra went on to say, "...I think I love you, Cal. ...Because you're not good" (p. 504). She took the reluctant Cal back to his father's death-bed for Cal's and Adam's salvation (p. 522). She would surely be a new family-member of the Trasks.

In *Journal of a Novel* Steinbeck praises Abra highly:

> Aron will develop to a certain extent but the powerful new people are Cal and Abra and a new Adam. And it is going to concentrate on them. The book has scattered a good deal. Now I feel that it must pull in tightly as it goes. All of the principles have been laid down except the principle of Abra. She is new to the book, the strong female principle of good as opposed to Cathy. Her strength will not be soft. Abra is a fighter and an effective human being. She will take active part in the battle. [27]

Here Steinbeck tries, it seems to me, to find his new hope in Abra. We have so far examined each character of the Trasks and their relatives in the three generations. When we see the Trask story as a whole, the scene similar to the Cain-Abel story is staged twice in the three generations of the Trasks. Adam and Charles were half-brothers, sons of Cyrus Trask. Cyrus loved Adam better than Charles. On his birth-day Cyrus received gifts from his sons and preferred Adam's one, a stray mongrel pup, to the fine pocket knife which Charles had given him after earning the money to buy it by cutting and selling a load of wood. In this way, a domestic animal was preferred to a product of a farmer's labor. In a jealous anger Charles beat Adam almost to death. Later Charles received a scar like Cain's mark on the forehead, while he was working in the field. Many years later, when Adam was living with Charles the badly hurt Cathy crawled up to the door of their house. Soon Adam fell in love with her, and married her. On the first night of the wedding day, she slept with Charles, and became pregnant. Adam preferred his son Aron, who in his boyhood raised Belgian hares (p. 259); the less liked Caleb wanted to go to farming (p. 376). Caleb loved his father Adam so passionately that he presented to him the money ($15,000) that he had made by a business venture. But Adam flatly rejected Cal's gift because he thought the money was made from war profit, and compared it with Aron's success in entering the university one year earlier. Caleb revenged himself by taking Aron to Cathy's whore-house. Aron was so shocked that he enlisted in the army early the next morning. A few days after Aron's enlistment, Adam asked Caleb where his brother was, and Caleb replied, "How do I know?...Am I supposed to look after him?" (p. 491). This is an inhuman remark, typical of the Cain characters.

In *The Grapes of Wrath* Jim Casy said, "Well, they was nice fellas, ya see. What made them bad was they needed stuff...." [28] But now Lee says that the Cain-Abel story is important because it is a story of rejection of love, from which all evil flows, since "with rejection comes anger, and with anger some kind of crime in revenge for the rejection, and with the crime guilt—and there is the story of mankind" (p. 235). Steinbeck himself states in Chapter 34: "I believe that there is one story in the world, and only one, that has frightened and inspired us, ...Humans are caught —...— in a net of good and evil. I think this is the only story we have and that it occurs on all levels of feeling and intelligence. ...In uncertainty I am certain that underneath their topmost layers of frailty men want to be good and want to be loved. Indeed, most of their vices are attempted short cuts to love. ...We have only one story. All novels, all poetry, are built on the never-ending contest in ourselves of good and evil" (pp. 359, 360). Now good and evil have become absolute and objective. On the other hand, in *In Dubious Battle* Doc Burton said, "...I want to see the whole picture—as nearly as I can. I don't want to put on the blinders of 'good' and 'bad', and limit my vision. ..."[29] And in *The Grapes of Wrath* Jim Casy said, "There ain't no sin and there ain't no virtue. There's just stuff people do...."[30] Concerning this problem, we notice a drastic change of the author's view. As for what makes man bad, in *The Grapes* Steinbeck mentions man's material want, while in *East* he points to the rejection of love. And in the preceding novels good and evil are relative and subjective. As Joseph Fontenrose points out, Steinbeck has limited his vision in *East of Eden*.[31] We can never be clear about the relationship between good and evil in this novel, for it is represented in four inconsistent ways: (1) Good is opposed to evil. Cyrus, Charles, Cathy, and Caleb have bad traits opposed to the good traits of Alice, Adam, Aron, and Abra. In the "thou mayest" doctrine, evil can be rejected and good chosen. (2) Good and evil are complementary. Adam's father Cyrus proved to be a thief. Cathy left the dirty money to the angel-like Aron. Lee wonders, "Was this some kind of joke or did things balance so that if one went too far in one direction an automatic slide moved on the scale and the balance was re-established?" (p. 507). (3) Evil is the source of good and may even be necessary to good. Lee said to Adam, "Saints can spring from any soil. Maybe with this money she would do some fine thing. There's no springboard to philanthrophy like a bad conscience" (p. 330). (4) Good and evil are relative terms. Lee said to Adam in the same speech, "What your wife is doing is neither good nor bad. ..." (p. 330). The relationship is inconsistent, and besides in its definition the remarks sometimes contradict each other. For instance, we are told that Cathy had no conscience (p. 61), and that she was operating the most depraved whorehouse in California (p. 266).

This novel mainly consists of the stories of "good" and "evil." Therefore, some scrutiny of the meaning of the words is necessary.

Good is identified both with admirable individual qualities and with conventional moral goodness. Evil is identified with ignoble individual qualities and with criminal acts. The definition of individual qualities include a very wide notion, so if we want to be strict, we should specify the meaning. Steinbeck evaluates admirable individual qualities, but they are abstract. For instance, Adam is honest and kind, we are told, but they are negative virtues in him. In fact virtue seems to be a function of lack of energy. George Hamilton's sinless life may be accounted for by pernicious anemia (p. 31), and Adam is passive, inert, and non-resistant.[32]

The following chart may rightly show the position of each character mentioned so far, according to Steinbeck's "C-A theme."

(C) (A)

|——|——|——|——|——|——|——|——|

Cathy Cyrus Charles Caleb Abra Adam (Alice)(Mr. and Mrs. Ames)Aron

Steinbeck's "good" seems to mean a negative goodness, that is, "not doing bad things positively." It smacks of inertness, anemicness, and negativeness. The character in its extremity is Aron who is too pure and self-indulgent to live on, bearing the burden of life. On the other hand, Steinbeck's "bad" means a positive bandness, that is, "doing bad things positively." The character in its extremity is Cathy who does the most ferocious acts. Here we see that Abra and Caleb positioned about the middle are the nearest to a real human being. Both of them have a capital letter of A and C as symbol people, but they are gifted with a wide potential of good and bad, as Steinbeck insists in the *Journal*.

3. Biblical Background of the Cain and Abel Story

Requested by Lee, Samuel Hamilton came to the Trasks again to name the twin brothers who had been left unnamed for over a year. He thought of the Cain-Abel story from their father's name Adam. He read to Adam and Lee Chapter 4 (1—16) of Genesis as follows:

> And Adam knew Eve his wife; and she conceived, and bare Cain,
> and said, I have gotten a man from the Lord.
> 2 And she again bare his brother Abel. And Abel was a keeper
> of sheep, but Cain was a tiller of the ground.
> 3 And in process of time it came to pass, that Cain brought of
> the fruit of the ground an offering unto the Lord.
> 4 And Abel, he also brought of the firstlings of his flock and of
> the fat thereof. And the Lord had respect unto Abel and to his
> offering.
> 5 But unto Cain and to his offering he had not respect. And Cain
> was very wroth, and his countenance fell.
> 6 And the Lord said unto Cain, Why art thou wroth? and why
> is thy countenance fallen?
> 7 If thou doest well, shalt thou not be accepted? and if thou
> doest not well, sin lieth at the door. And unto thee *shall be* his de-
> sire, and thou shalt rule over him.
> 8 And Cain talked with Abel his brother: and it came to pass,
> when they were in the field, that Cain rose up against Abel his
> brother, and slew him.
> 9 And the Lord said unto Cain, Where *is* Abel thy brother? And
> he said, I know not: *Am* I my brother's keeper?
> 10 And he said, What hast thou done? the voice of thy brother's
> blood crieth unto me from the ground.
> 11 And now *art* thou cursed from the earth, which hath opened
> her mouth to receive thy brother's blood from thy hand;
> 12 When thou tillest the ground, it shall not henceforth yield
> unto thee her strength; a fugitive and a vagabond shalt thou be
> in the earth.
> 13 And Cain said unto the Lord, My punishment *is* greater than
> I can bear.
> 14 Behold, thou hast driven me out this day from the face of the
> earth; and from thy face shall I be hid; and I shall be a fugitive

> and a vagabond in the earth; and it shall come to pass, *that* every one that findeth me shall slay me.
> 15 And the Lord said unto him, Therefore whosoever slayeth Cain, vengeance shall be taken on him sevenfold. And the Lord set a mark upon Cain, lest any finding him should kill him.
> 16 And Cain went out from the presence of the Lord, and dwelt in the land of Nod, on the east of Eden.

This is the story of man's sin following the story of the Fall of Man, where the first man and woman, Adam and Eve, committed a sin. Steinbeck did not take the material for this novel from the story of Seth and his offspring whom God blessed, but he took it from the story of Cain whom God condemned, permanently branded as the wanderer on the earth and banished to the east of Eden. Though the Cain-Abel story does not mention Cain's faith, the New Testament refers to his faith. For instance, Paul suggests in the Apostle to the Hebrews Cain's fragile faith:

> 4 By faith Abel offered unto God a more excellent sacrifice than Cain, by which he obtained witness that he was righteous, God testifying of his gifts: and by it he being dead yet speaketh.
> (Hebrews 11:4)

John is far more critical toward Cain in The First Epistle General of John:

> 11 For this is the message that ye heard from the beginning, that we should love one another.
> 12 Not as Cain, *who* was of that wicked one, and slew his brother. And wherefore slew he him? Because his own works were evil, and his brother's righteous. (John 3:11—12)
> 15 Whosoever hateth his brother is a murderer: and ye know that no murderer hath eternal life abiding in him. (John 3:15)

Jude, brother of James, states in The General Epistle of Jude:

> 10 But these speak evil of those things which they know not: but what they know naturally, as brute beasts, in those things they corrupt themselves.
> 11 Woe unto them! for they have gone in the way of Cain, and ran greedily after the error of Ba'laam for reward, and perished in the gainsaying of Co're. (Jude 10—11)

Besides the above, there are some references which reveal that the offerers' mental attitude is more important than the gifts themselves: Samuel 15:22, Isaiah 1:11—17, and Psalms 50:8—15.

Though God saved Cain his life, Apostles in the later years all branded Cain as the condemned, as the one not deserving the eternal life and walking the path to peril. They all denied the possibility of his recovery from the sin. On the other hand, Steinbeck sees the prototype of man in the condemned Cain and examines whether those who are driven to the extreme of sin can be saved or not. He does not look for the prototype of man in those whom God blessed, such as Seth, Noah, and Abraham. This is perhaps because if the condemned can be saved, then the blessed are naturally saved. Steinbeck's idea about salvation is concentrated on the verse of Genesis 4:7: "And unto thee shall be his desire, and thou shalt rule over him." The problem was discussed at the two meetings among the three, — Samuel, Lee, and Adam. The discussion which appears in Part 2 and 3 of Chapter 24 seems to provide the conclusion. "Thou shalt rule over him" stipulated in the King James version reveals God's promise that Cain would conquer sin, while "Do thou rule over him" in the American Standard Bible is God's order. Concerning this problem, Steinbeck interprets through the mouth of Lee: it is neither God's promise nor God' order in the Hebrew word "*timshel*" (p. 263). The word should, he insists, be interpreted as "Thou mayest." "Thou mayest" of course allows for "Thou mayest not" (p. 263). Here is man's free will and free choice in recovery from sin. Steinbeck acknowledges that his interpretation is contradictory to Christian doctrine (p. 264), and at the same time he points out the importance the interpretation bears toward man (p. 264). "Thou mayest" makes a man great. It gives him stature with gods (p. 264). In order to be equal to gods, however, he must possess enough potentiality for it. In this connection, Steinbeck seems to insist that the individual is a unit of morals by saying, "And this I believe; that the free, exploring mind of the individual human is the most valuable thing in the world. And this I would fight for: the freedom of the mind to take any direction it wishes, undirected" (pp. 111—112). Steinbeck also seems to regard this "free, exploring mind of the individual human" as divine, in view of his firm determination to fight for it. This phrase reminds us of Jim Casy's remark "Maybe all men got one big soul ever'body's a part of."[33] In short, Steinbeck acknowledges the individual's potentiality of having stature with gods. By the new interpretation of the word "*timshel*," Steinbeck tries to open the way for salvation (pp. 263—264). It is far from the recovery from sin which is promised or ordered by God. For "Thou mayest" puts a great importance upon man: man's emancipation from God and man's independence from God. It puts a great stress on the responsibility of man. If it is God's promise or God's order, Cain will be lost, and man descended from Cain can not be saved. In spite of the above remark, however, God is not slighted at all. For it is God that stipulates "Thou mayest." Steinbeck tries to find man's salvation by God, not in the relationship between God and man but in that between man and man.

Steinbeck interprets the word "*timshel*" rather definitely in the novel, but actually he himself is a little uncertain about the interpretation: "I was very glad of your (Pascal Covici's) last letter. And the translation of the word. Don't worry about. I will have to get the best answers. And if there is an argument I am all right. Don't forget that in the Jewish translation you sent, they did not think '*timshel*' was a pure future tense. They translated it 'thou mayest.' This means that at least there is a difference of opinion and that is enough for me. I will have to have the whole verb before I will finish, from infinitive on through past, subjunctives and compounds and futures. But we will get it. We may have to go outside of rabbinical thought to pure scholarship which may be non-Jewish. ... Dr. Ginzberg, dealing in theology, may have a slightly different attitude from that of a pure etymologist. We know that the other translations were warped by what the translators wished to be there. Words are strange elusive things and no man may permanently stick them on pins or mount them in glass cases" (JS-PC, 7/6/51)[34]. He goes on to say "Your last letter which suggests 'thou canst' moves even closer to free will than 'thou mayest.' And if there is still difference of opinions among scholars, my point is made" (JS-PC, 7/14/51)[35].

Joseph Fontenrose, however, objects to Steinbeck's new interpretation of the word: "That verse (Genesis 4:7) has an obviously corrupt text, and the sentence at issue appears to be out of place. For one thing, the masculine pronouns cannot refer to 'sin,' which translates a Hebrew feminine noun. And *timshol* will not bear the meaning which Steinbeck puts upon it. He apparently read or was told that the Hebrew imperfect tense, which indicates incomplete action at any time, is used where English employs either the vivid future tense (*will, shall*) or the potential (*would, should, may, might*); in either case the action is unfulfilled. If a translation as potential suited this verse, it would be simply 'you would rule'; it cannot be a permissive 'may.' Steinbeck, furthermore, constantly translates *timshol* 'thou mayest,' dropping 'rule,' as if the Hebrew form were simply an auxiliary."[36] On the other hand, Fontenrose generously tolerates Steinbeck's "faulty translation": "Many a sermon, however, has drawn a fine meaning from a faulty translation of a corrupt text."[37] The present writer has no means to make sure whether it is a "faulty translation" or not. But at least we can agree to Fontenrose's generous conclusion.

Fontenrose further delves into the origin of the Cain-Abel story: " Steinbeck read a great deal about Genesis while writing *East of Eden* and probably came upon a later Jewish legend (current before 300 A.D.) which elaborates the brief and bare scriptural narrative: both Cain and Abel had a twin sister, each intended to become her twin's wife and so ensure the survival of mankind. Abel's twin sister was so beautiful that Cain wanted her; therefore he picked a quarrel with Abel, killed him, and married Abel's twin, that mysterious wife of Cain who bore his son Enoch in the land of Nod (Genesis 4:17)."[38] By citing the Jewish legend, Fontenrose tries to explain the rivalry over a woman (Cathy and Abra) in both generations of brothers (Charles and Adam, and Caleb and Aron).

II. Eastern Philosophy

1. Lee, the Chinese Servant, and the Four Old Chinese Gentlemen

Steinbeck explains in the *Journal* how he needed Lee, the Chinese servant: "I want to go a little into Cathy today and also into Lee the Chinese. I have known so many of them. Remarkable people the California Chinese. ... Now you are going to like Lee. He is a philosopher. And also he is a kind and thoughtful man. And beyond all this he is going to go in the book because I need him. The book needs his eye and his criticism which is more detached than mine. I have a fine early start today so I shall get to it soon. Starts with Cathy, goes to Lee, brings in Samuel. And then Samuel's relationship with Lee, and Lee's relationship to Adam and to Cathy. Lee's attitudes will if anything be clearer than mine. Also Lee has to raise the boys."[39] Lee, who first appears in Chapter 15, is generally said to be meant as the spokesman for Steinbeck. But judging from the above remark, he is a figure gifted with a far more penetrating view of life than the author's. Lee's new interpretation of the word "*timshel,*" worked out through the cooperation of the four old Chinese gentlemen, gives a clue to Samuel's and Adam's salvation of soul. Moreover, Lee influences Caleb and Abra very much by his philosphy. Steinbeck tries to create the new type of a man and a woman in Caleb and Abra respectively, and perhaps wants to entrust them with the future of man.

Lee's philosophy and thought is not necessarily limited to that of the East. But rather it is universal and is deeply based in man's reason. The secret of his birth itself, however, reveals part of the wretched situations of the imported Chinese "human cattle" (p. 313). The following rather exclamatory and repeated remarks of Lee's, it seems ot me, are meant to show his own homing instinct: "I seem to get more Chinese as I get older" (p. 254)./"... I told you, Mr. Hamilton, that I was growing more Chinese. Do you ever grow more Irish?" (p. 261)./ "I told you I was getting more Chinese. Well, to go on, I went to San Francisco to the headquarters of our family association. ..."(p. 262)/"... I began to love my race, and for the first time I want to be Chinese. ..." (p. 263).

Also his repeated references to things Chinese—Chinese traditions, manners, and customs —are perhaps meant to show the background of Lee's Eastern philosophy. The history of Lee's parents and the secret of his own birth is pathetically told by him in five pages. It starts with "I'll have to tell you first that when you built the railroads in the West the terrible work of grading and laying ties and spiking the rails was done by many thousands of Chinese" (p. 311), and ends with "My father always told it at the last: No child ever had such care as I. The whole camp became my mother. It is a beauty—a dreadful kind of beauty. And now good night. I can't talk any more" (p. 315). This story seems to show the ugliness of the Chinese laborers who killed his pregnant mother by raping and the beauty of the same people who tried to atone for the guilt as the whole camp by nursing the new-born motherless baby. Here Lee finds man's power of recovery from his guilt.

Steinbeck portrays Lee through Cathy's eyes when he first appears: "His face was lean and pleasant, his forehead broad, firm, and sensitive, and his lips curled in a perpetual smile. His long black glossy braided queue, tied at the bottom with a narrow piece of black silk, hung over his shoulder and moved rhythmically against his chest. When he did violent work he curled his queue on top of his head. He wore narrow cotton trousers, black heel-less slippers, and a frogged Chinese smock. Whenever he could he hid his hands in his sleeves as though he were afraid for them, as most Chinese did in that day" (p. 137).

When Samuel first meets Lee, he asks Lee why they the Chinese still talk pidgin (p. 139). Lee cites three reasons for it: "It's more than a convenience, ... It's even more than self-protection. Mostly we have to use it to be understood at all" (p. 139). Lee explains the third reason: "Pidgin they (ladies or gentlemen) expect, and pidgin they'll listen to. But English from me they don't listen to, and so they don't understand it" (p. 139). Samuel asks another question, "If you cut your queue, dressed and talked like other people?" (p. 140). Lee replies, "No, I tried it. To the so-called whites I was still a Chinese, but an untrustworthy one; and at the same time my Chinese friends steered clean of me. I had to give it up" (p. 140). Lee dares to say, "Talkee Chinese talk. Queue Chinese fashion—you savvy?" (p. 140). Lee is so completely disappointed with and has so completely despaired of the racist American society where only pidgin is expected of the Chinese people that he never hopes to be active on the surface of the society. But instead he chooses to be a servant.

Lee explains the position of a servant to Samuel: "I don't know where being a servant came into disrepute. It is the refuge of a philosopher, the food of the lazy, and, properly carried out, it is a position of power, even of love. I can't understand why more intelligent people don't take it as a career—learn to do it well and reap its benefits. A good servant has absolute security, not because of his master's kindness, but because of habit and indolence. It's a hard thing for a man to change spices or lay out his own sock. He'll keep a bad servant rather than change. But a good servant, and I am an excellent one, can completely control his master, tell him what to think, how to act, whom to marry, when to divorce, reduce him to terror as a discipline, or distribute happiness to him, and finally be mentioned in his will. If I had wished I could have robbed, stripped, and beaten anyone I've worked for and come away with thanks. Finally, in my circumstances I am unprotected. My master will defend me, protect me. You have to work and worry. I work less and worry less. And I am a good servant. A bad one does no work and does no worrying, and he still is fed, clothed, and protected. I don't know any profession where the field is so cluttered with incompetents and where excellence is so rare" (pp. 141—142).

Lee is enjoying his life of unrestrained, free will, most unnoticed as a servant. One day, when Samuel asks Lee whether he is a Presbyterian, Lee replies, "She (Liza) thought I should be something, and I went to Sunday School long ago in San Francisco. People like you to be some thing, preferably what they are" (p. 232). On another occasion, when Samuel says, "I just wanted to know, ... You're not a Presbyterian after all," Lee responds, "I told you I was getting more Chinese. ..." (p. 262). Lee indirectly negates that he is a Presbyterian. He goes on to negate his belief in any religion, saying, "I have no bent toward gods" (p. 294). Preceding this remark, however, he states: "Confucius tells men how they should live to have good and successful lives. But this—this is a ladder to climb to the stars." Lee's eyes shone. "You can never lose that. It cuts the feet from under weakness and cowardliness and laziness" (p. 264). This reveals that Lee is fundamentally a Confucian as most of the Chinese people used to be. At the same time the following remarks of Lee's reveal an attitude toward life which seems contradictory to Confucians': "...Finally, in my circumstances I am unprotected. My master will defend me, protect me. You have to work and worry. I work less and worry less. And I am a good servant...." (p. 142)./ "But I take my two pipes in the afternoon, no more and no less, like the elders. And I feel that I am a man...." (p. 264). We can safely call his leisurely, unrestrained attitude "Taoist."

Lee's remark to Abra, "I'm a servant. I'm old. I'm Chinese" (p. 431), shows Lee's fundamental self-recognition. He has shared the tragic fortune of the Chinese people since his birth, and the society expects pidgin of them; on the other hand China is no longer their mother country. Out of such circumstances, Lee must have acquired a penetrating view of life as a philospher-servant. He sees humans as being caught and distressed in good and evil, not from the present phase, but from the permanent phase. This can be done only through the peculiarity of his blood. It is obvious that his philosophy and thought is deeply rooted in Eastern philosophy. This has much in common with Steinbeck's non-teleological thinking.

Next let us examine the curious episode of the four old Chinese gentlemen who have studied the word "*timshel*" with Lee for over two years. Lee explains why he went to San Francisco to the headqurters of his family association: "I went there because in our family there are a number of ancient reverend gentlemen who are great scholars. They are thinkers in exactness. A man may spend many years pondering a sentence of the scholar you call Confucius. I thought there migh be experts in meaning who could advise me" (p. 262). The old scholars are Confucians as well as Lee, who study each sentence of the *Analects*. At the same time the following remarks of Lee's reveal that the old scholars are Taoists who are absorbed in their discussion, free from worldliness, like the "Seven Sages in the Bamboo Forest" in ancient China: "They are fine old men. They smoke their two pipes of opium in the afternoon and it rests and sharpens them, and they sit through the night and their minds are wonderful.

I guess no other people have been able to use opium well" (p. 262)./ "I guess it's funny, ... I know I wouldn't dare tell it to many people. Can you imagine four old gentlemen, the youngest is over ninety now, taking on the study of Hebrew? They engaged a learned rabbi. They took to the study as though they were children. Exercise books, grammar, vocabulary, simple sentences. You should see Hebrew written in Chinese ink with a brush! The right to left didn't bother them as much as it would you, since we write up to down. Oh, they were perfectionists! They went to the root of the matter" (p. 263).

Lee studies with them for over two years. He admires them, saying, "I went along with them, marvelling at the beauty of their proud clean brains. I began to love my race, and for the first time I wanted to be Chinese. ..." (p. 263). The old Chinese scholars give Lee a clue to his understanding of the word "*timshel.*" The following quotation seems to show that they are not necessarily Christians.

> Adam said, "Do you mean these Chinese men believe the Old Testament?"
> Lee said, "These old men believe a true story, and they know a true story when they hear it. They are critics of truth. They know that these sixteen verses are a history of humankind in any age or culture or race. They do not believe a man writes fifteen and three-quarter verses of truth and tells a lie with one verb."
> (p. 264)

Thus, we can say that both Lee and the old scholars are fundamentally Confucians and at the same time Taoists. Their thought is deeply rooted in Eastern philosophy. They are too American to look like real Chinese, but they are still meant to represent Eastern philosophy.

2. Confucianism and Taoism (Lao-tzu and Chung-tzu)

In this novel the word "Confucius" appears twice—at pages 262 and 264—, while the word "Taoism" or "Lao-tzu" never once appears. But the fact that Steinbeck was well versed in Lao-tzu is revealed in his reference to Lao-tzu in *Cannery Row*. Steinbeck's favorite idea "non-teleological thinking" has much in common with Lao-tzu. He cites Lao-Tze (tzu) in the second place among Plato, Buddha, Christ, Paul, and the great Hebrew prophets as the "great ones" in the *Journal*.[40] This shows his great interest in Lao-tzu. On the other hand, the word "Taoism" never once appears in *East of Eden*. We can see, however, a Taoist attitude in the Chinese characters' leisurely daily life, detached from worldliness.

In order to understand Eastern philosophy represented by these characters, let us examine the two conflicting thoughts: confucianism and Taoism. The study of Chinese thought starts with Confucius (551—479 B.C.) and Lao-tzu, most likely Confucius' contemporary. The two are the leading personalities in the whole history of Chinese culture. Confucius was no doubt a most learned scholar in his day. He was a *ju* (man of letters), indeed, and also a thinker, though not along the line pursued by the Taoists, especially by Chuang-tzu; he was also a great educator, in this respect quite different from both Lao-tzu and Chuang-tzu. The Taoists were thoroughly individualistic and were not concerned very much with affairs that did not belong to them. They were thus apt to be passive egoists and pacifists. When asked to be a state minister, Chuang-tzu flatly turned down the offer, but he chose to live a free life. His free spirit could not be broken to any kind of civil service whatever.

Confucius was, on the other hand, an eager office-hunter who wished to get an appointment under one of the feudal dukes. He traveled from state to state until he felt he was too old. Then he finally abandoned the idea of putting his theories into practice and began to teach and educate his followers. Probably he was a strict disciplinarian, especially in conduct, though without neglecting the cultivation of refined feeling. The *Analects* gives a detailed account of Confucius' behavior when he once happened to hold a somewhat important government position somewhere.[41]

At the center of the Confucian system is humanity, or *jen* in Chinese. "*Jen* is to love men," Confucius said (*Analects of Confucius,* chap. 12, section 22). *Jen* might also be translated as benevolence, love, manhood, or human-heartedness. To Confucius, *jen* is the essence of humanity, that element in man which makes a man man and which distinguished him from an animal. *Jen* is endowed by nature but should be cultivated by man, and the greatness of man is measured by the extent of the development of *jen* in him. Jen is so essential to man that the preservation of one's *jen* is considered more important than the preservation of one's life, and it is so central in the teaching of Confucius that the system might be said to be the philosophy of *jen*.

The virtue of filial piety and those of loyalty and reciprocity were also stressed by Confucius, and they might be regarded as expressions of *jen* within the family and in social relations respectively. The Confucian golden rule has become well known— "Do not do to others what one does not wish to be done unto" —(*Analects of Confucius,* chap. 12, section 2), and Confucius also said, "Wishing to be established oneself he assists others to be established; wishing to be successful oneself he assists others to be successful" (*Analects of Confucius,* chap. 6, section 28). The teachings of Confucius underline the kinship of all men and advocate the expression of the spontaneous good will toward one another. "*Jen* is to love men joyously and from the innermost of one's heart," runs an ancient commentary on the *Analects*. The famous saying, "Within the four seas, all men are brothers," (*Analects of Confucius,* chap. 12, section 5) comes from a disciple of Confucius.

Coupled with the basic concept of *jen* and the several related virtues was Confucius' emphasis on the cultivation of decorum and music —a twofold emphasis representing the master's dual feeling for the moral and the aesthetic. Speaking of the development of one's personality, Confucius said, "It is by poetry that one's mind is aroused; it is by ceremonials that one's character is regulated; it is by music that one becomes accomplished" (*Analects of Confucius,* chap. 8, section 8). The cultivation of decorum and music would afford an element of grace in the individual and civility in society. The proper cultivation and combination of *jen* and decorum were the requisites to the perfection of the individual and the restoration of order out of chaos, according to Confucius. Just as a house with a solid foundation should have a pleasing facade, so should a man with an abundance of good will take care to express it with thoughtfulness and good manners.[42]

Lao-tzu was a solitary thinker with no personal followers, and nobody recorded his dates of birth and death. As to his doings while living, he is mentioned only as having been a custodian of the Chou ducal documents. His lack of attention was in accordance with his philosophical attitude. The *Tao Te Ching* ascribed to him is an immortal work in which he expounds his ethical paradox of *wei wu wei,* "doing not-doing," and those who put it into practice would remain unnoticed by the public even after death. We are thankful, however, to him for having left this masterly piece of philosophical wisdom. Confucius was great in his way, no doubt, but without Lao-tzu Chinese thought would have been the poorer and the world would have missed a unique contribution to its thought-treasure.

The *Tao Te Chiang* contains Lao-tzu's reflections on Tao as the regulating principle of human conduct, and a man here is conceived as an individuality and also as a member of the community. When we come from *Analects* to the *Tao Te Ching,* we find the latter to be in most striking contrast to the former. What Confucius would strongly affirm as very essential for a good government Lao-tzu would flatly deny, and say that the world does not go as it should just because of such teachings as those of Confucius and his followers. Lao-tzu boldly asserts: "Benevolence and justice come into vogue because of the Great Tao going out of use. Human contrivance (*ta-wei*) rises because of knowledge and intelligence having evolved." Thus Lao-tzu categorically negates benevolence (*jen*), while Confucius would teach that its promotion is the highest of all human virtues. The Confucian school is known as *Ju-chiao* : *ju* means "a scholar" and *chiao*, "teaching"; while Lao-tzu's school is called *Tao-chiao, tao* meaning "the way."

Chuang-tzu was the greatest of the philosophers, poets, and literary essayists in the entire history of the Taoist School—more than that, perhaps in all fields of Chinese literature. His writings consist altogether of thirty-three essays under the general title of the *Chuang-tzu.* These are mostly stories and anecdotes, real and fictitious, which are supposed to have taken place between various classes of people: Confucians, Taoists, statesmen, scholars, feudal lords, artisans, farmers, fishermen, butchers, criminals, and so forth. The main trend of these stories is the elucidation from various points of view of the author's philosophy of life, Nature, and human relations. Not only are Lao-tzu's ideas brought out here in contrast to the Confucian but they are presented in entrancing style and mastery finish.

In all likelihood Confucianism in those days was the stronger, lording it over all other schools. The Pre-Chin period was, indeed, the most flourishing one in the history of Chinese philosophy and there is no doubt that the Confucian teaching was the one that most appealed to the Chinese mentality. With all Chuang-tzu's poetic genius, logical acumen, and mystical imagination, the Taoist movement could not turn Confucianism away from its historical course, though this does not mean that the Chinese have been altogether averse to the Taoist way of thinking.[43] In short, Confucianism is the main stream of Eastern philosophy, and Taoism is the by-stream which serves to enrich the philosophy.

As I have previously mentioned, Lao-tzu has much in common with Steinbeck's favorite idea of "non-teleological thinking." For instance, The *Tao Te Ching* written by Lao-tzu explains the idea of "Tao." It begins with the following remarks:

> Ch. 1. 1. The Tâo that can be trodden is not the enduring and unchanging Tâo. The name that can be named is not the enduring and unchanging name.
> 2. (Conceived of as) having no name, it is the Originator of heaven and earth; (conceived of as) having a name, it is the Mother of all things.

It goes on to explain the "Tao."

> Ch. 25. 1. There was something undefined and complete, coming into existence before Heaven and Earth. How still it was and formless, standing alone, and undergoing no change, reaching everywhere and in no danger (of being exhausted)! It may be regarded as the Mother of all things.
>
> 2. I do not know its name, and I give it the designation of the Tao (the Way or Course). Making an effort (further) to give it a name I call it the Great.
>
> ....
>
> 4. Man takes his law from the Earth; the Earth takes its law from Heaven; Heaven takes its law from the Tao. The law of the Tao is its being what it is.[44]

Let us compare the above with the following quoted remarks from *The Log from the Sea of Cortez:*

> Non-teleological ideas derive through "is" thinking, associated with natural selection as Darwin seems to have understood it. They imply depth, fundamentalism, and clarity—seeing beyond traditional or personal projections. They consider events as outgrowths and expressions rather than as results; conscious acceptance as a desideratum, and certainly as an all important prerequisite. Non-teleological thinking concerns itself primarily not with what should be, or could be, or might be, but rather with what actually "is" —attempting at most to answer the already sufficiently difficult questions *what* or *how*, instead of *why*.[45]
>
> The frequent allusions to an underlying pattern have no implication of mysticism—except inasmuch as a pattern which comprises infinity in factors and symbols might be called mystic. But infinity as here used occurs also in the mathematical aspects of physiology and physics, both far away from mysticism as the term is ordinarily employed. Actually, the underlying pattern is probably nothing more than an integration of just such symbols and indices and mutual reference points as are already known, except that its power is *n*."[46]

In this comparison we can see great similarities: "Tao" seems to be almost equal to an "underlying pattern," and the former is as omnipresent as the latter. Especially, the following remark explicitly shows the great similarity between the two concepts of "being."

> The whole is necessarily everything, the whole world of fact and fancy, body and psyche, physical fact and spiritual truth, individual and collective, life and death, macrocosm and microcosm (the greatest quanta here, the greatest synapse between these two), conscious and unconscious, subject and object. The whole picture is portrayed by *is*, the deepest word of deep ultimate reality, not shallow or partial as reasons are, but deeper and participating, possibly encompassing the Oriental concept of *being*.[47]

3. Chinese Traditions, Manners, and Customs

Next let us examine some typical Chinese traditions, manners, and customs which seem to constitute the background of Eastern philosophy.

a. Chinese Characteristics:

In this novel the adjective "Oriental" is often used to denote the unmistakable characteristics of the Chinese people as follows: "And Lee, let me caution you about bringing your *Oriental reasoning* to Liza's attention" (p. 234)./"...And what do you think of my *Oriental patter,* Mr. Hamilton? You know I am no more *Oriental* than you are" (p. 236)./ "No," said Lee, "I was not making a joke. In my obscure but courteous *Oriental manner* I was indicating to you that I would prefer to know your opinion before I offered mine" (p. 328). / He (Lee) thought ruefully, 'I wonder what happened to my *Oriental repose*' (p. 389)./ Lee laughed. "My *Oriental calm* seems to have deserted me," he said. "Let me make the tea, darling. I'll get hold of myself that way" (p. 509). (italics mine)

b. Chinese Demonology:

When Lee is talking with Samuel about the strangeness of the Adam-Cathy house, Lee says, "...Since I've come here I find myself thinking of Chinese fairy tales my father told me. We Chinese have a well-developed demonology" (p. 163). After a year, Lee, Samuel, and Adam get together to name the twin brothers. When asked by Samuel whether the Chinese have any ghosts, Lee replies, "Millions, ... We have more ghosts than anything else. I guess nothing in China ever dies. It's very crowded. Anyway, that's the feeling I got when I was there" (p. 229). Actually, the dogma, prevailing in China from the earliest times, that the Universe is filled in all its parts with shen and kwei, naturally implies that devils and demons must also swarm about the homes of men in numbers inestimable. It is, in fact, an axiom which constantly comes out in conversing with the people, that they haunt every frequented and lonely spot, and that no place exists where man is safe from them. Even the privy is not respected, and the numerous narratives, transmitted by books and by word of mouth about people frightened, maltreated and killed there, point explicitly to a tendency of spectres to select preferably for their cruel and malign exploits those malodorous spots, where man is so lonely and helpless. Public roads are infested and haunted by them everywhere, especially during the night, when the power of the yin part of Nature, to which spectres belong especially, is strongest.[48] In fact some books on China tell us about the omnipresence and multitude of demons.

c. Chinese Funeral:

When Lee and Adam are talking about Samuel's funeral, Lee happens to mention Chinese funeral: "My people bury them with drums and scatter papers to confuse the devils and put roast pigs instead of flowers on the grave. We're a practical people and always a little hungry. But our devils aren't very bright. We can out-think them. That's some progress" (p. 287). Let us examine drums or signalheads, paper-scattering, and food-offering mentioned in the above dialogue.

(Paper-Scattering)

A distant relation, a friend or an acquaintance, likewise dressed in a white robe and cap, is to strew round or octangular sheets of tinned paper, from eight to ten centimetres in diameter, along the road, and also in the water when the train has to cross a creek or stream by a bridge or in boats. A great number of these sheets, strung on a little stick like metal coins on a cord, he carries in his hands for the purpose. This paper money is destined for the malevolent spirits who, according to the popular conception, prowl about everywhere and infest streets and thoroughfares, mountains and forests, rivers and creeks, causing all sorts of mishap to befall men. Wisely concluding that great numbers of these beings, hungry and miserable because of their not having been cared for by a dutiful posterity, must be swarming chiefly on the roads where coffins have to pass, for the express purpose of robbing, by importunate begging or by brute force, every deceased person of the money wherewith the living have so unselfishly enriched him during the funeral rites, the measure in question is recurred to in order to divert their attention. Like famished wolves on their prey, the spirits rush upon the money, and thus forgetting, both coffin and soul, permit the procession to pass by unmolested.[49]

(Signalheads or Drums)

Though the unseen spirits may be propitiated by such liberal gifts of paper money, these are by no means deemed a decisive expedient to keep them at a respectable distance from the funeral train. Two long trumpets of copper, with a thin sliding tube and curved-up mouth, are still required to frighten away those among them on whom the distribution of money has no effect. These instruments, which are called "signalheads", are not proper musical instruments, as they only give two or three notes; the men who carry them behind the paper-scatterer simply emit monotonous, protracted sounds through them at intervals.[50] For the same purpose drums are alse used.

(Food-Offering)

The ancient Chinese did by no means confine themselves to placing food at the side of the dead only once. They also supplied a sumptuous meal the next day, after the dead man was dressed for the grave. The modern Chinese still faithfully maintain this usuage. Neither do they deviate from the ways of their ancestors in placing food near the corpse after it has been enclosed in the coffin. If we now call to mind the rooted belief of the Chinese of all ages that the soul does not abandon the body after death, it appears quite natural the conviction arose at a very early date that it is the soul which enjoys the food, as nobody ever saw the body touch it. The numerous presentations of edibles and liquors to the dead body even after it has been nailed up in an enclosure of six substantial planks, are in this way easily accounted for.[51]
The above accounts prove that Chinese funeral has much to do with Chinese demonology.

d. Chinese Manners and Customs:

(Sleeve-Hidden Hands)

When Lee first appears in the novel, he "wore narrow cotton trousers, black heel-less slippers, and a frogged Chinese smock. Whenever he could he hid his hands in his sleeves as though he were afraid for them, as most Chinese did in that day" (p. 137). Lee's clothes are considered typical of Chinese laborers. As for sleeve-hidden hands, it is said to be the remnant of the ancient Chinese courtesy. It has something to do with the customary Chinese clothes with wide sleeves.

(Queue)

When Lee makes his first appearance, he also wears a queue. "His long black glossy braided queue, tied at the bottom with a narrow piece of black silk, hung over his shoulder and moved rhythmically against his chest. When he did violent work he curled his queue on top of his head" (p. 137). When Samuel first sees Lee, samuel asks a question of Lee, "...For instance, you wear the queue. I've read that it is a badge of slavery imposed by conquest by the Manchus on the Southern Chinese .... Then why in the name of God do you wear it here, where the Manchus can't get at you?" (pp. 139—140). Lee replies, "Talkee Chinese talk. Queue Chinese fashion—you savvy?" (p. 140). As Samuel says, the Ching dynasty of the Manchus started to conquer the whole China in the 1630's. About 1645, when the conquest was almost over, the dynasty forced the Southern Chinese to wear a queue. In those days there were quite a few who tried to escape from the enforcement by becoming monks or by committing suicide. By the end of the dynasty, however, it had settled to be a custom. [52]

(Debt-Clearing)

When Lee is explaining the tragedy of his parents, he mentions the Chinese custom: "You must know that a Chinese must pay all of his debts on or before our New Year's Day. He starts every year clean. If he does not, he loses face; but not only that—his family loses face. There are no excuses" (p. 311). In China, the ways of celebrating New Year Days are rooted in Confucianism and Taoism. The celebrations are observed, following the lunar calendar. New Year Days are very important to the Chinese people. Usually the preparation for the Days starts a week before. The celebrations last for five days. [53] It is quite natural that the Chinese people think that they should start every year clean as Lee explains, because the Days are so important to them. The fact that the family loses face unless the man pays all of his debts is related with the Chinese big-family system.

(Big-Family System)

Lee explains the Chinese big-family system to Adam: "All Chinese are related, and the ones named Lee are closest" (p. 421). In traditional China the institution of prime importance was the family, and indeed dominant principle of a righteous life was considered to be allegiance to one's parents (hsiao, translated "filial piety," was one of Confucius cardinal virtues). Confucian teachings regarding the sanctity of relationships between family members and setting forth mutually protective functions for them were at bottom the same as his ideals for government, which he conceived of as a kind of large family.

The family, as idealized in traditional China and, frequently, even today, was a joint family made up of several small patrilineally related units, covering perhaps five generations. This family lived under one roof and functioned as a single cooperating unit in all its activities —economic, religious, and social. Its members might work at a combination of occupations—agricultural, business, and governmental—and by such concerted effort the united family might be able to achieve wealth and prestige. The structure of this ideal family was hierarchical, according to generation, age, and sex. It was headed by the eldest male, who wielded complete power over all the family members. The headship usually passed to the eldest son, or sometimes to the son adjudged most worthy. Wives, brought into the husband's joint household through family rather than individual decision, were subservient to the husband's mother and to other family members. [54]

When we have examined the Chinese manners and customs, we can not help being impressed with the breadth and depth of the influence of Confucianism upon the daily life of the Chinese people.

III. Correlation between Christianity and Eastern Philosophy

So far, we have examined how much Lee represents Eastern philosophy, not being just the spokesman for Steinbeck, while both the Hamiltons and the Trasks represent the Christian world. Perhaps, here we can safely examine the correlation between Christianity and Eastern philosophy by putting Lee versus the two families. After the process of examining the correlation between Lee and the rest of the two families, we will come to the climactic correlation between Lee and Adam, in which Adam succeeds in working out his own salvation.

1. Lee versus Cathy, the Monster Woman, and Liza

When Lee first came to Cathy to offer tea, her "eyes inspected him and her inspection could not penetrate the dark brown of his eyes. He made her uneasy. Cathy had always been able to shovel into the mind of any man and dig up his impulses and his desires. But Lee's brain gave and repelled like rubber" (p. 137). Lee shuffled away to the kitchen with his hands hidden in his sleeves. "Cathy looked after him, and her eyebrows drew in a scowl. She was not afraid of Lee, yet she was not comfortable with him either. But he was a good and respectful servant—the best. And what harm could he do her?" (p. 137).

Samuel, who has first visited the Trask house, says, "By God, I got creepy! Is there something wrong here?" (p. 150). Lee replies, "Chinese boy jus' workee—not hear, not talkee" (p. 150). But he simply reveals his intention to leave the Trasks, saying, "Do you need a cook?" (p. 150). On the next occasion, on Lee's way back from the errand of inviting Samuel because of Cathy's childbirth, Lee talks with Samuel:

> "I guess that's all it is with me too," said Lee. He smiled. "I'll tell you how far it got with me, though. Since I've come here I find myself thinking of Chinese fairy tales my father told me. We Chinese have a well-developed demonology."
> "You think she is a demon?"
> "Of course not," said Lee. "I hope I'm a little beyond such silliness. I don't know what it is. You know, Mr. Hamilton, a servant develops an ability to taste the wind and judge the climate of the house he works in. And there's a strangeness here. Maybe that's what makes me remember my father's demons."
> "Did your father believe in them?"
> "Oh, no. He thought I should know the background. You Occidentals perpetuate a good many myths too." (p. 163)

Soon after Cathy's bite at Samuel's hand, Lee and Samuel scare each other. Lee says, "I think I'll go away, ... I never went willingly to a slaughter-house" (p. 169). Here again Lee reveals his intention to leave the Trask's, but it is impossible to do that because of the deserted newborn babies. After Cathy's departure, Lee never sees Cathy again. Just once Lee utters a rather sympathetic remark to comfort the troubled Adam, and persuades him to tell the truth about Charles' legacy: "What your wife is doing is neither good nor bad. Saints can spring from any soil. Maybe with this money she would do some fine thing. There's no springboard to philanthropy like a bad conscience" (p. 330). Later, however, when Lee is asked by Cal about Cathy, he tells Cal, "... She (Cathy) is a mystery. It seems to me that she is not like other people. There is something she lacks. Kindness maybe, or conscience. You can only understand people if you feel them in yourself. And I can't feel her. The moment I think about her my feeling goes into darkness. I don't know what she wanted or what she was after. ... It's a mystery. ... " (p. 388). On the other hand, when Adam appears again before Cathy to tell her about the legacy problem, Cathy mentions Lee: "How about that Chinaman? He's smart" (p. 335). After all Cathy is a "mystery" to Lee, while Lee is merely a smart Chinaman to Cathy. Cathy, the monster-woman without human conscience, is the last person to be influenced by Lee.

At first, when Liza comes to help Adam, "Lee she used like a slave since she did not quite believe in him" (p. 172). Later, however, Liza admires Lee, saying, "Well, wouldn't you say off-hand he was a heathen? ... Come now, Samuel, anybody would. But he's not. .... A Presbyterian, and well up—well up, ... And I say yes. Well now, who do you think is looking after the twins? I wouldn't trust a heathen from here to omega—but a Presbyterian—he learned everything I told him" (p. 173). Samuel responds, "No wonder they're taking on weight" (p. 173). Liza goes on, "It's a matter for praise and its a matter for prayer" (p. 173). Later Lee proves to be no Presbyterian at all, and to have "no bent toward gods" (p. 264). Liza is a champion of the Christian world. Lee and Liza are quite different in their respective belief. Liza's "faith is a mountain" (p. 214), while Lee has "no bent toward gods" (p. 264). Nevertheless, they have much in common, though they are not influenced by each other. Their attitude toward life is adamant, like "pillars of fire" which guide" frightened men through darkness" (p. 268): the former's fire emanates from Christianity, while the latter's from Eastern philosophy based in human reason.

2. Lee versus Aron, Caleb, and Abra

The twin brothers who have been brought up by Lee are now eleven years old. When Samuel visits the Trasks for the last time, he talks with Lee about the brothers.

> "They are big. I'm glad I stayed here. I learned a great deal from seeings the boys grow and helping a little."
> "Did you teach them Chinese?"
> "No. Mr. Trask didn't want me to. And I guess he was right. It would have been a needless complication. But I'm their friend—yes, I'm their friend. They admire their father, but I think they love me. And they're very different. You can't imagine how different."
> "In what way, Lee?"
> "You'll see when they come home from school. They're like two sides of a medal. Cal is sharp and dark and watchful, and his brother—well, he's a boy you like before he speaks and like more afterwards."
> "And you don't like Cal?"
> "I find myself defending him—to myself. He's fighting for his life and his brother doesn't have to fight." (p. 255)

When the bothers are high scool students, they suffer from their father's failure in the lettuce venture. They become a laughing stock of the town, and are called "lettuce head." Especially, Aron is so sensitive and so hurt that he wants to go away from the town. He even does not inform his father of his succsee in the entrance exam. Lee tries to comfort him, hands on the broad shoulders: "'You're growing up. Maybe that's it,' he said softly. 'Sometimes I think the world tests us most sharply then, and we turn inward and watch ourselves with horror. But that's not the worst. We think everybody is seeing into us. Then dirt is very dirty and purity is shining white. Aron, it will be over. Wait only a little while and it will be over. That's not much relief to you because you don't believe it, but it's the best I can do for you. Try to believe that things are neither so good nor so bad as they seem to you now. Yes, I can help you. Go to bed now, and in the morning get up early and tell your father about the tests. Make it exciting. He's lonelier than you are because he has no lovely future to dream about. Go through the motions. Sam Hamilton said that. Pretend it's true and maybe it will be. Go through the motions. Do that. And go to bed. I've got to bake a cake—for breakfast. And, Aron—your father left a present on your pillow'" (p. 427).

On Thanksgiving Day, Lee, Adam, and Aron, talk about Aron's future course. Lee enthusiastically tells his idea about a specialist to them: "Maybe the knowledge is too great and maybe men are growing too small, ... Maybe, kneeling down to atoms, they're becoming atom-sized in their souls. "Maybe a specialist is only a coward, afraid to look out of his little cage. And think what any specialist misses—the whole world over his fence" (p. 470). Next, he tells about money: "Money's easy to make if it's money you want. But with a few exceptions people don't want money. They want luxury and they want love and they want admiration" (p. 470). Last, he tells about college: "You're right, I do seem to get too excited. No, if college is where a man can go to find his relation to his whole world, I don't object. Is it that?" Is it that, Aron?" (p. 470). While Lee is away to the kitchen, Adam admires Lee, saying, "What a good man! What a good friend!" (p. 470). Aron also shows his affection toward Lee, saying, "I hope he lives to be a hundred" (p. 470). Later Aron volunteers to go to war and is killed there. He is so self-indulgent that even Lee can not influence him enough to enable him to face squarely the realities.

Next, let us examine the relationship between Lee and Caleb: "With Lee, Cal's trick did not work, for Lee's bland mind moved effortlessly ahead of him and was always there waiting, understanding, and at the last moment cautioning quietly, 'Don't do it.' Cal had respect for Lee and a little fear of him" (p. 327). Requested by Cal, Lee tells the truth about Cal's mother, Cathy: "I've thought about it for a great many hours and I still don't know. She is a mystery. It seems to me that she is not like other people. There is something she lacks. Kindness maybe, or conscience. You can only understand people if you feel them in yourself. And I can't feel her. The moment I think about her my feeling goes into darkness. I don't know what she wanted or what she was after. She was full of hatred, but why or toward what I don't know. It's a mystery. And her hatred wasn't healthly. It wasn't angry. It was heartless. I don't know that it is good to talk to you like this" (p. 388). Next, Lee tells about Adam: "I think your father has in him, magnified, the things his wife lacks. I think in him kindness and conscience are so large that they are almost faults. They trip him up and hinder him" (p. 388). Lee tries to comfort Cal, saying, "I don't think your father ever hated her. He had only sorrow" (p. 389), but Cal reveals his great despondency:

> "It's like you said about knowing people. I hate her because I know why she went away. I know—because I've got her in me." His head was down and his voice was heart-broken.
>
> Lee jumped up. "You stop that!" he said sharply. "You hear me? Don't let me catch you doing that. Of course you may have that in you. Everybody has. But you've got the other too. Here—look up! Look at me!"
>
> Cal raised his head and said wearily, "What do you want?"
>
> "You've got the other too. Listen to me! You wouldn't even be wondering if you didn't have it. Don't you dare take the lazy way. It's too easy to excuse yourself because of your ancestry. Don't let me catch you doing it! Now—look close at me so you will remember. Whatever you do, it will be you who do it—not your mother." (p. 389)

Later, when at last Cal sees what Cathy really is, he says, "I was afaid I had you in me. ... No. I haven't. I'm my own. I don't have to be you. ... I just know. It came to me whole. If I'm mean, it's my own mean" (p. 404). As Cathy complains, "This Chinaman has really fed you some pap," Lee's lesson proves to be not in vain. Some time after he has fallen into despondency because of the rejected love, Cal seems to have come to a resolution. Lee tries to dissuade him from carrying it out, saying, "Stop it."

> Lee said uneasily, "I told you once when you asked me that it was all in yourself. I told you you could control it—if you wanted."
>
> "Control what? I don't know what you're talking about."
>
> Lee said, "Can't you hear me? Can't I get through to you? Cal, don't you know what I'm saying?"
>
> "I hear you, Lee. What are you saying?"
>
> "He couldn't help it, Cal. That's his nature. It was the only way he knew. He didn't have any choice. But you have. Don't you hear me? You have a choice."
>
> The spirals had become so small that the pencil lines ran together and the result was a shiny black dot.
>
> Cal said quietly, "Aren't you making a fuss about nothing? You must be slipping. You'd think from your tone that I'd killed somebody. Come off it, Lee. Come off it." (p. 473)

Cal is resolved to do something revengeful against his father. Even Cal, however, is so distressed and guilt-ridden due to Aron's two nights' absence that he becomes more and more despondent. Lee severely charges Cal; "Don't make it complicated, ... You know why you did it. You were mad at him, and you were mad at him because your father hurt your feelings. That's not difficult. You were just mean" (p. 495). Cal cries, "I guess that's what I wonder—why I'm mean. Lee, I don't want to be mean. Help me, Lee!" (p. 495). Lee informs Cal of Cathy's suicide, and he gives a lesson to Cal, charging him with too much self-consciousness.

> "You're pretty full of yourself. You're marvelling at the tragic spectacle of Caleb Trask—Caleb the magnificent, the unique. Caleb whose suffering should have its Homer. Did you ever think of yourself as a snot-nose kid—mean somtimes, incredibly generous sometimes? Dirty in your habits, and curiously pure in your mind. Maybe you have a little more energy than most, just energy, but

> outside of that you're very like all the other snot-nose kids. Are you trying to attract dignity and tragedy to yourself because your mother was a whore? And if anything should have happened to your brother, will you be able to sneak for yourself the eminence of being a murderer, snot-nose?"
>
> Cal turned slowly back to his desk. Lee watched him, holding his breath the way a doctor watches for the reaction to a hypodermic. Lee could see the reactions flaring through Cal—the rage at insult, the belligerence, and the hurt feelings following behind, and out of that—just the beginning of relief.
>
> Lee sighed. He had worked so hard, so tenderly, and his work seemed to have succeeded. He said softly, "We're a violent people, Cal. Does it seem strange to you that I include myself? Maybe it's true that we are all descended from the restless, the nervous, the criminals, the arguers and brawlers, but also the brave and independent and generous. If our ancestors had not been that, they would have stayed in their home plots in the other world and starved over the squeezed-out soil."
>
> Cal turned his head towards Lee, and his face had lost its tightness. He smiled, and Lee knew he had not fooled the boy entirely. Cal knew now it was a job—a well-done job—and he was grateful.
>
> Lee went on, "That's why I include myself. We all have that heritage, no matter what old land our fathers left. All colours and blends of Americans have somewhat the same tendencies. It's a beeed—selected out by accident. And so we're over-brave and over-fearful—we're kind and cruel as children. We're over-friendly and at the same time frightened of strangers. We boast and are impressed. We're over-sentimental and realistic. We are mundane and materialistic—and do you know of any other nation that acts for ideals? We eat too much. We have no taste, no sense of proportion. We throw our energy about like waste. In the old lands they say of us that we go from barbarism to decadence without an intervening culture. Can it be that our critics have not the key or the language of our culture? That's what we are, Cal—all of us. You aren't very different."
>
> "Talk away," said Cal, and he smiled and repeated, "Talk away."
>
> "I don't need to any more," said Lee. "I'm finished now. I wish your father would come back. He worries me." And Lee went nervously out. (pp. 496—497)

Cathy's suicide and Aron's death cause Adam to suffer a stroke. Adam lies in bed almost unconscious. Lee comforts Cal, saying, "I'm sorry, Cal. Bear up! You'll have to bear up. ... It always surprises me how people bear up. They always do" (p. 518). And then Cal confesses his sin to the unconscious father: "I'm responsible for Aron's death and for your sickness. ..." (p. 519).

It is after Aron has gone to college that Abra often visits Adam's. She trusts Adam and Lee better than her own father (p. 427). Lee "likes Abra and he felt strength and goodness in her, and warmth too. Her features had the bold muscular strength which could result finally either in ugliness or in good beauty" (p. 428). Lee prefers Abra to Chinese beauty (p. 428).

He listens to Abra's criticism toward Aron: "I thought he always felt—well, kind of crippled —maybe unfinished, because he didn't have a mother. ... Just absolutely pure. Nothing but pure—never a bad thing. I'm not like that" (pp. 428, 430). She complains that it makes her uneasy (p. 430). Lee comforts her, saying, "Nobody is" (p. 430). When Lee is asked by Abra whether Mrs. Trask is alive, he refuses to answer the question, saying, "Abra, let me tell you about myself. I'm a servant. I'm old. I'm Chinese. These three you know. I'm tired and I'm cowardly" (p. 431). Soon later, however, he replies softly, "Yes," acknowledging that Cathy is alive. When Abra comes to the Trasks, requested by Lee, Lee utters unawares to Abra: "I wish you were my daughter—" ,while Abra says to Lee, "I wish you were my father" (p. 508).

Lee gives her a "small, dark green jade button," his mother's only ornament, as a present. She kisses the jade and then Lee. This seems to be the adoption ritual in which Lee and Abra become affiliated as father and daughter. Lee tells Abra about Cal: "He (Cal)'s crammed full to the top with every good thing and every bad thing. I've thought that one single person could almost with the weight of a finger—" (p. 509).

Suggested by Lee, Cal goes to his father lying almost unconscious in bed and confesses his sin: "I did it, ... I'm responsible for Aron's death and for your sickness. I took him to Kate's. I showed him his mother. That's why he went away. I don't want to do bad things—but I do them" (p. 519). Though he confesses, his father's eyes seem to pursue him. Lee comforts Cal, telling him that anything he sees in Adam's eyes may be pressure on that part of his brain. Cal still insists: "He accused me. I know it. He said I'm a murderer" (p. 520). Lee answers, "Then he will forgive you. I promise" (p. 520). Lee advises Cal to go to Abra. When Cal goes there, Abra takes back to the Trasks the unwilling Cal who says he would like to go away to escape the father's pursuing eyes. Abra requests Lee to help Cal (p. 523). Then Lee reflects himself on his own wrong ideas and gives a very solemn and sublime lesson to Abra and Cal.

> Abra put her elbows on the kitchen table. "Help him," she said. "You can accept things, Lee. Help him."
>
> "I don't know whether I can accept things or not," Lee said. "I've never had a chance to try. I've always found myself with some—not less uncertain but less able to take care of uncertainty. I've had to do my weeping—alone."
>
> "Weeping—? You?"
>
> He said, "When Samuel Hamilton died the world went out like a candle. I relighted it to see his lovely creations, and I saw his children tossed and torn and destroyed as though some vengefulness was at work. Let the ng-ka-py run back on your tongue."
>
> He went on, "I had to find out my stupidities for myself. These were my stupidities: I thought the good are destroyed while the evil survive and prosper.
>
> "I thought that once an angry and disgusted God poured molten fire from a crucible to destroy or to purify his little handiwork of mud.
>
> "I thought I had inherited both the scars of the fire and the impurities which made the fire necessary—all inherited, I thought. All inherited. Do you feel that way"
>
> "I think so," said Cal.

> "I don't know'" Abra said.
> Lee shook his head. "That isn't good enough. That isn't good enough thinking. Maybe——" And he was silent.
> Cal felt the heat of the liquor in his stomach. "Maybe what, Lee?"
> "Maybe you'll come to know that every man in every generation is re-fired. Does a craftsman, even in his old age, lose his hunger to make a perfect cup—thin, strong, translucent?" He held his cup to the light. "All impurities burned out and ready for a glorious flux, and for that—more fire. And then either the slag heap or, perhaps what no one in the world ever quite gives up, perfection." He drained his cup and he said loudly, "Cal, listen to me. Can you think that whatever made us—would stop trying?"
> "I can't take it in." Cal said. "Not now I can't." (p.523)

In this moving statement, Lee stresses the responsibility of the individual and insists that every individual should face and withstand the fire of life, and that he only can be a true man when he has come through the fire.

3. Lee versus Samuel and Adam

Lee first visits Samuel on an errand from Adam. His errand is to ask Samuel to come and talk about well-digging in the Adam's new place. On his way to Adam's, Samuel asks Lee some questions about things Chinese: first pidgin and then queue. Lee answers, "Talkee Chinese talk. Queue Chinese fashion—you savvy?" (p. 140). Then Lee praises Samuel, saying, "That's why I'm talking to you. You are one of the rare people who can separate your observation from your preconception. You see what is, where most people see what they expect" (p. 139). Samuel answers, "I hadn't thought of it. And I've not been so tested as you, but what you say has a candle of truth. ..." (p. 139). Thereupon, they become good friends. They discuss the position of a servant. Lee insists that as a servant "I work less and worry less" (p. 142), but he admits that it is a "lonely life" (p. 142).

Adam is so dazed by Cathy's departure that he leaves his new-born babies unnamed for over a year. When Samuel hears about it from Lee, he becomes indignant. He tries to shock Adam from moral lethargy by knocking down Adam. Adam has a far-away yet intent look, as if he were listening to some wind-carried music, but his eyes are not dead as they have been. He expresses his thanks to Samuel: "It's hard to imagine I'd thank a man for insults and for shaking me out like a rug. But I'm grateful. It's a hurty thanks, but it's thanks" (p. 225). Samuel admires Lee who has been taking good care of the babies, saying to Adam, "He (Lee) trusts you now, ... He has a gift of resigned loyalty without hope of reward. He's maybe a much better man than either of us could dream of being" (p. 230). When it comes to naming of the twin brothers, Samuel mentions unawares the Cain-Abel story from his association of the name of Adam (p. 231). Lee gives his own Oriental interpretation of the story (p. 234). He goes on to say: "... And I here make a rule—a great and lasting story is about everyone or it will not last. The strange and foreign is not interesting—only the deeply personal and familiar. ... The greatest terror a child can have is that he is not loved, and rejection is the hell he fears. I think everyone in the world to a large or small extent has felt rejection. And with rejection comes anger, and with anger some kind of crime in revenge for the rejection, and with the crime guilt—and there is the story of mankind. I think that if rejection could be amputated, the human would not be what he is. Maybe there would be fewer crazy people. I am sure in myself there would not be many jails. It is all there—the start, the beginning. One child, refused the love he craves, kicks the cat and hides his secret guilt; and another steals so that money will make him loved; and a third conquers the world—and always the guilt and revenge and more guilt. The human is the only guilty animal. Now wait! Therefore I think this old and terrible story is important because it is a chart of the soul—the secret, rejected, guilty soul. Mr. Trask, you said you did not kill your brother and then you remembered something. I don't want to know what it was, but was it very far apart from Cain and Abel? And what do you think of my Oriental patter, Mr. Hamilton? You know I am no more Oriental than you are" (pp. 235—236). After the naming, Adam thanks Samuel and says, "I'm glad you came, ... There is a weight off me" (p. 237). And at the same time Adam declares his loss of hope for the Garden: "I think that kind of energy is gone out of me. I can't feel the pull of it. ... I have no one to show a garden to" (p. 237). Samuel comforts Adam, his eyes filled with tears, saying, "Don't think it will ever die, ... Don't expect it. ... I tell you it won't ever die until you do" (p. 237).

About ten years later, when Samuel visits Adam for the last time, his efforts prove to be in vain. For Adam has not changed much (p. 255), and has left the land fallow (p. 256). Adam even says challengingly to Samuel: "We had that out before. You thought I would change. I've not changed" (p. 256). Samuel says at last, "You have never let her (Cathy) go" (p. 256). Adam admits it: "I guess not. ... "(p. 256). Samuel praises Lee, while being critical to Adam, saying, "Adam, I wonder whether you know what you have in Lee. A philosopher who can cook, or a cook who can think? He has taught me a great deal. You must have learned from him, Adam" (p. 260). Adam confesses miserably: "I'm afraid I didn't listen enough—or maybe he didn't talk" (p. 260). Then, Lee begins to tell the story about his assidious study of the word "*timshel*" :

> "I went along with them (the four old Chinese gentlemen), marvelling at the beauty of their proud clean brains. I began to love my race, and for the first time I wanted to be Chinese. Every two weeks I went to a meeting with them, and in my room here I covered pages with writing. ... The American Standard translation *orders* men to triumph over sin, and you can call sin ignorance. The King James translation makes a promise in 'Thou shalt', meaning that men will surely triumph over sin. But the Hebrew word, the word *timshel*—'Thou mayest'—that gives a choice. It might be the most important word in the world. That says the way is open. That throws it right back on a man. For if 'Thou mayest'—it is also true that 'Thou mayest not.' Don't you see?"
>
> "Yes, I see. I do see. But you do not believe this is divine law. Why do you feel its importance?"
>
> "Ah!" said Lee. "I've wanted to tell you this for a long time. I even anticipated your questions and I am well prepared. Any writing which has influenced the thinking and the lives of innumerable people is important. Now, there are many millions in their sects and Churches who feel the order, 'Do thou,' and throw their weight into obedience. And there are millions more who feel pre-

> destination in 'Thou shalt'. Nothing they may do can interfere with what will be. But 'Thou mayest'! Why, that makes a man great, that gives him stature with the gods, for in his weakness and his filth and his murder of his brother he has still the great choice. He can choose his course and fight it through and win." Lee's voice was a chant of triumph.
>
> Adam said, "Do you believe that, Lee?"
>
> "Yes, I do. Yes, I do. It is easy out of laziness, out of weakness, to throw oneself into the lap of deity, saying, 'I couldn't help it; the way was set.' But think of the glory of the choice! That makes a man a man. A cat has no choice, a bee must make honey. There's no godliness there. And do you know, those old gentlemen who were sliding gently down to death are too interested to die now." (pp. 263—264)

When leaving Adam and Lee for the last time, Samuel tells the truth about Cathy: "Cathy is in Salinas. She owns a whore-house, the most vicious and depraved in this whole end of the country" (p. 266). This has been meant by Samuel as the second shock-therapy for Adam. Thereupon, startled, Adam runs away into the darkness from the scene. For his great courage of telling the truth, Lee praises Samuel (p. 267). Samuel tells the reason for his disclosure of the truth:

> "'Thou mayest rule over sin,' Lee. That's it. I do not believe all men are destroyed. I can name you a dozen who were not, and they are the ones the world lives by. It is true of the spirit as it is true of battles—only the winners are remembered. Surely most men are destroyed, but there are others who like pillars of fire guide frightened men through the darkness. *'Thou mayest, Thou mayest!'* What glory! It is true that we are weak and sick and quarrelsome, but if that is all we were, we would, millenniums ago, have disappeared from the face of the earth. A few remnants of fossilised jawbone, some broken teeth in strata of limestone, would be the only mark man would have left of his existence in the world. But the choice, Lee, the choice of winning! I had never understood it or accepted it before. Do you see now why I told Adam to-night? I exercised the choice. Maybe I was wrong, but by telling him I also forced him to live or get off the pot. What is that word, Lee?"
>
> "*Timshel,*" said Lee. "Will you stop the cart?" (pp. 268—269)

This time, Lee praises Samuel, "Samuel, you've gone beyond me" (p. 269). Some months later, Samuel dies as Lee has predicted while talking with him: "There's death all around you. It shines from you" (p. 268). Adam attends the funeral service, but unwillingly because he can not believe that Samuel is dead (p. 270). After the funeral service, he visits Cathy and sees what she really is. He laughs pleasantly, saying, "Now I see you, I mean. You know, I guess it was Samuel said I'd never seen you, and it's true. I remember your face but I had never seen it. Now I can forget it" (p. 277). Even when Adam is cruelly told by Cathy that the twin-brothers are not his children but Charles', he is upset no longer. On his way home he drops in at Will Hamilton's garage in King City to order an automobile. Adam admires Samuel, saying to Will, "I don't know whether you know how I felt about your father. He gave me things I will never forget. ... Such a man doesn't really die, ... I can't think of him as dead.

He seems maybe more alive to me than before" (p. 285). The above shows that Adam is so much influenced by Samuel that after his death Adam feels Samuel more alive.

On his drive home to the ranch, he finds himself noticing things he has not seen in the field for years. When he comes to his own ranch he feels a pleasure so sharp that he finds himself saying aloud in rhythm with the horses' feet: "I'm free, I'm free. I don't have to worry any more. I'm free. She' gone. She's gone out of me. Oh, Christ Almighty, I'm free!" (p. 287). He touches a wild sage and he eagerly wants to see the twins.

Adam feels a deep affection toward Charles now. He first writes to Charles in over ten years, asking Charles to come west to him. Soon he receives a letter from Charles' lawyer to the effect that Charles has bequeathed his fortune to be divided equally between Cathy and him. Adam hesitates to ensure the half of the fortune to Cathy, but Lee insists on Adam's following the direction of the will:

> "Maybe you'll have to think for your brother," said Lee. "What your wife is doing is neither good nor bad. Saints can spring from any soil. Maybe with this money she would do some fine thing. There's no springboard to philanthropy like a bad conscience."
> Adam shivered. "She told me what she would do if she had money. It was closer to murder than to charity."
> "You don't think she should have the money, then?"
> "She said she wonld destroy many reputable men in Salinas. She can do it too."
> "I see," said Lee. "I'm glad I can take a detached view of this. The pants of their reputations must have some thin places. Morally, then, you would be against giving her the money?"
> "Yes." (p. 330)

After the heated discussion and on his second thought, however, Adam finally gives way to Lee. Adam again visits Cathy and tells her about Charles' bequeath of his fortune. She can not understand him. He leaves her, saying, "I think you are only a part of a human"(p.336). Later, Adam is appointed to be on the draft board. He ponders his responsibility of sending boys to the battle field. He talks with Lee:

> "I was thinking about that time when Sam Hamilton and you and I had a long discussion about a word," said Adam. "What was that word?"
> "Now I see. The word was *timshel*."
> "*Timshel*—and you said——"
> "I said that word carried a man's greatness if he wanted to take advantage of it."
> "I remember Sam Hamilton felt good about it."
> "It set him fiee," said Lee "It gave him the right to be a man, separate from every other man."
> "That's lonely."
> "All great and precious things are lonely."
> "What is the word again?"
> "*Timshel*—thou mayest." (p. 453)

When Adam is told that Cathy has committed suicide, he weeps bitterly, crying, "Oh, my poor darling!" (p. 490). Adam again wears a "dazed look." Aron's letter that he has enlisted in the army shocks Adam so completely that he falls ill. As a final touch, the report of Aron's death drives him to a stroke. Adam lies in bed almost unconscious. Cal confesses his sin, but Adam's eyes seem to pursue him. Lee desperately pleads with Adam in the presence of both Cal and Abra.

> Lee's shoulders straightened. He said sharply, "Your son is marked with guilt of himself—out of himself—almost more than he can bear. Don't crush him with rejection. Don't crush him, Adam."
>
> Lee's breath whistled in his throat. "Adam, give him your blessing. Don't leave him alone with his guilt. Adam, can you hear me? Give him your blessing!"
>
> A terrible brightness shone in Adam's eyes and he closed them and kept them closed. A wrinkle formed between his brows.
>
> Lee said, "Help him, Adam—help him. Give him his chance. Let him be free. That's all a man has over the beasts. Free him! Bless him!" (p. 525)

After his great struggle in response to Lee's persistent persuasion, Adam utters, "*timshel*" in the air and falls into a sleep. Adam seems to have worked out his own salvation through Lee's kind and enthusiastic persuasion.

Conclusion

As the title suggests, the main theme of this novel is centered on a modern version of the Cain-Abel story in the Old Testament. At first Steinbeck intended to tell the story of the Hamilton family, his maternal parents', for his two sons, and then he introduced the Trask family as the neighbors of the Hamiltons. As he proceeded in writing, however, the importance shifted to the Trasks. As a result, the history of the Hamiltons only serves to give breadth and depth to the Trask story. Besides, notwithstanding Steinbeck's original intention, the Hamilton story became the requiem for the family, because Steinbeck put too much stress on the death of Una, Dessie and Tom, and Samuel.

Following what Steinbeck called "my C-A theme," the main figures in the Trask story are classified into two groups, the Cain and the Abel characters. After the desperate struggle between C and A, the central figure Adam narrowly gains the salvation of his soul. And the very person that guides Adam to his salvation is Lee, the Chinese servant. In *Journal of a Novel* Steinbeck tells Pascal Covici about Lee that Lee is a "philosopher" and a "thoughtful and kind man," and that Steinbeck needs his eye which is "more detached" than his. But Steinbeck does not make it clear whether Lee is a Christian or not. In the novel, however, Lee says to Adam, "I have no bent toward gods." And yet he highly praises the glory of man's free choice of his course. His interest in philosophy and thought is not necessarily limited to that of the East. But rather it is universal and is deeply rooted in man's reason. At the same time, the secret of his birth itself reveals part of the plight of the imported Chinese "human cattle." Lee's frequent remark "I seem to get more Chinese as I get older," is meant to show his homing instinct. Also Lee's repeated references to things Chinese—Chinese traditions, chracteristics, manners, and customs—are perhaps meant to be the background of his Eastern philosophy. Lee enjoys his life of unrestrained, free will, most unnoticed as a servant. Moreover, there is a curious episode of the four old Chinese gentlemen who have studied the word "*timshel*" with

Lee for two years. Lee tells Samuel about the old gentlemen that they are "thinkers in exactness" who "may spend many years pondering a sentence of the scholar you call Confucius" (p. 262), and that they are "critics of truth." Lee goes on to say that "Confucius tells men how they should live to have good and successful lives. But this—this is a ladder to climb to the stars. ..." (p. 264). The above remarks seem to reveal that Lee and the old gentlemen are fundamentally Confucians, as most Chinese used to be. And at the same time their attitude in life is Taoist. Lee's following remarks afford one more glimpse into this philosophical posture: "They are fine old men. They smoke their two pipes of opium in the afternoon and it rests and sharpens them, ..." (p. 262)/ "But I take my two pipes in the afternoon, no more and no less, like the elders. ..." (p. 264).

East of Eden describes Adam's progression with Lee's guidance from mere goodness to his salvation. For instance, soon after the twin's birth, Cathy deserts Adam and the new-born babies. Adam is so shocked that he does not take care of or give names to the babies. Through Lee's instigation, Samuel Hamilton strikes Adam into an awareness of the twins. About ten years later, Samuel again tries to shock Adam out of his moral lethargy by informing him of the truth about Cathy. This blow actually begins his awakening. Now he sees Cathy as she is. Even when he is told by her that the twins are Charles' children, he is not a bit upset. On his drive back from Cathy's whore-house, he finds himself saying aloud: "I'm free, I'm free. ... She's gone out of me. ..." (p. 287).

Later, seriously shocked by the news of Aron's death, Adam suffers a stroke and lies in bed nearly unconscious. Though Caleb confesses his sin to his father, Adam's eyes seem to pursue him. Lee desperately pleads with Adam, saying, "Adam, glve him your blessing. Don't leave him alone with his guilt. ... Give him your blessing!" (p. 525). Lee finally succeeds in his desperate and persistent persuasion. There comes a whisper out of Adam's struggling body and he says, "*Timshel*!" Having reached his salvation of soul, Adam falls into a sleep.

As we can see, at first the interpretation of the Cain-Abel story is given by Lee and the four old Chinese gentlemen. Secondly, Adam is awakened to his spiritual needs and responsibility by Lee. Lastly, Adam is guided to his salvation by Lee. Lee and the old Chinese gentlemen are too Chinese-American, so they do not look like real Chinese. They are still meant, however, to represent Eastern philosophy. Therefoıe, we can conclude that Christianity, greatly stimulated by Eastern philosophy, leads to Adam's salvation.

NOTES

[1] John Steinbeck, *Journal of a Novel* (New York : Viking Press, 1969), p. 4. Abbreviations : JS=John Steinbeck, PC=Pascal Covici.

[2] *Ibid.*, p. 8.

[3] *Ibid.*, p. 124.

[4] Peter Lisca, *The Wide World of John Steinbeck* (New Brunswick, N.J. : Rutgers Univ. Press, 1958), p. 269.

[5] *Ibid.*, p. 275.

[6] *Ibid.*, p. 262.

[7] *Ibid.*, p. 262.

[8] *Ibid.*, pp. 262—263.

[9] Lester J. Marks, *Thematic Design in the Novels of John Steinbeck* (The Hague : Mouton, 1969),

p. 115.

[10] Hideo Inazawa, *A Study of Steinbeck* (*Sutainbekk-ron*) (Tokyo : Shicho-sha, 1967), p. 54.

[11] Steinbeck, *Journal*, p. 65.

[12] Marks, *Thematic Design*, p. 117.

[13] *Ibid.*, p. 117.

[14] *Ibid.*, p. 115.

[15] John Steinbeck, *Cannery Row* (London : Heinemann, 1971), p. 9.

[16] John Steinbeck, *East of Eden* (London : Heinemann, 1965), p. 1. Subsequent page references to the novel will be given in parentheses immediately after the quotation.

[17] Steinbeck, *Journal*, p. 143.

[18] *Ibid.*, p. 140.

[19] *Ibid.*, p. 140.

[20] *Ibid.*, p. 58.

[21] *Ibid.*, p. 103.

[22] Shotaro Oshima, *English Literature and Poetic Imagination* (Tokyo : Hokusei-do, 1972), p. 13.

[23] Steinbeck, *Journal*, p. 7.

[24] *Ibid.*, p. 27.

[25] *Ibid.*, p. 65.

[26] *Ibid.*, p. 128.

[27] *Ibid.*, p. 146.

[28] John Steinbeck, *The Grapes of Wrath : Text and Criticism* ed. Peter Lisca (New York : Viking Press, 1972), p. 521.

[29] John Steinbeck, *In Dubious Battle* (London : Heinemann, 1970), p. 115.

[30] Steinbeck, *The Grapes*, pp. 31—32.

[31] Joseph Fontenrose, *John Steinbeck : An Introduction and Interpretation* (New York : Holt, Rinehart and Winston, 1963), p. 124.

[32] *Ibid.*, pp. 124—126.

[33] Steinbeck, *The Grapes*, p. 33.

[34] Steinbeck, *Journal*, pp. 121—122.

[35] *Ibid.*, p. 129.

[36] Fontenrose, *John Steinbeck*, pp. 123—124.

[37] *Ibid.*, p. 124.

[38] *Ibid.*, p. 122.

[39] Steinbeck, *Journal*, p. 73.

[40] *Ibid.*, p. 115.

[41] D.T. Suzuki, "Introduction," in *The Tao Te Ching and the Writings of Chuang Tzu* trans. and ed. James Legge (Taihoku : Bunsei-shoten, 1963), pp. 1—7.

[42] Y.P. Mei, "Confucius : On Humanity and Decorum" in *Encyclopedia Americana* Vol. 7 (New York : Americana Corporation, 1968), pp. 541—542.

[43] D.T. Suzuki, "Introduction," pp. 1—6.

[44] James Legge, trans. and ed. *The Tao Te Ching and the Writings of Chuang Tzu*, pp. 95, 115—116.

[45] John Steinbeck, *The Log from the Sea of Cortez* (New York : Viking Press, 1968), p. 135.

[46] *Ibid.*, p. 149.

[47] *Ibid.*, pp. 150—151.

[48] J.J.M. DE GROOT, "Disposal of the Dead," *The Religious System of China* Vol. V (Taipei : Cheng-Wen Publishing Co., 1969), p. 470.

[49] *Ibid.*, Vol. 1, p. 154.

[50] *Ibid.*, Vol. 1, p. 155.

[51] *Ibid.*, Vol. 1, p. 360.

[52] Yoshio Hosotani, "Pigtail (Benpatsu)," *Encyclopedia Japonica* Vol. 16 (Tokyo : Shogakkan, 1971), p. 323.

[53] Nojin Sato, "New Year Days in China (Chugoku no Shogatsu)," *Encyclopedia Japonica* Vol. 9, p. 376.

[54] Rita Schlesinger Callin, "China : Social Life and Custom," *Encyclopedia Americana* Vol. 6, p. 501.

往復正放物線カムの研究（第1報）

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Studies on the Parabolic Profile Cam with a reciprocating Follower (Report 1)

——Circular Arc Follower——

Hironori ITOSHIMA

The profile of the cam consists of a base circle and a parabolic curve. The reciprocating follower, which is offset from the pivot of the cam, is a roller or a circular arc mushroom follower. And the profile of the cam is expressed in xy coordinates.

In this paper, the motion (displacement, velocity and acceleration) of the reciprocating follower is analysed, and the pressure angle, the offset and the specific sliding are examined.

If the lift of the follower, the pressure angle at the starting point, the maximum specific sliding of the cam and the radius of the base circle are specified, then the radius of the arc and the offset of the follower are decided.

If the ratio of the acceleration of the follower at the starting point and the end point is specified, then each size of the best cam can be designed.

§1 緒　　言

放物線の輪郭をもつカムの基礎円の中心を回転軸とし，かたより円弧（ローラ）従動節に往復運動を与えるカム機構において，回転xy座標をカム上に，上下運動するXY座標を従動節上に固定し，従動節の運動（変位，速度，加速度）をカム上の位置を示すパラメーターδを用いて解析し，さらに押進め角，滑り率を求めて，それらの最大値を調べ，放物線カムの性質を論ずる。

次に最大押進め角，最大加速度，カムの最大滑り率を低くなるように，往き行程の始点あるいは終点の押進め角，加速度，滑り率を指定して，このカム機構の最適寸法を定める。

§2 記　　号

a：カムの回転中心と放物線の頂点との距離

b：カムの中心から放物線までのy軸上の長さ

R_0：基礎円の半径

θ：カムの回転角

θ_0：往き行程のカムの回転角

θ_r：戻り行程のカムの回転角

k：始点における従動節の中心の高さ

e：かたより量

r：従動節の円弧半径

H：従動節のリフト

δ：y軸とカムの半径のなす角

δ_0：運動の始点におけるδ

ω：カムの角速度

ϕ：押進め角

h：従動節の変位
$dh/d\theta$：従動節の速度$=\omega dh/d\theta$
$d^2h/d\theta^2$：従動節の加速度$=\omega^2 d^2h/d\theta^2$
ρ_T：カムの曲率半径
σ_1：カムの滑り率
σ_2：従動節の滑り率
α：作用角

§3　往復正放物線カムの機構

図1に示すように中心O，半径 R_0 の基礎円に接する放物線CADをもつカムがO点を回転中心として反時計回りにωの角速度で回転し，半径rの円弧（ローラ）をもつ往復従動節がO点よりeだけかたよった行程線Y軸上を上下するカム機構である。

O点を原点として行程線に平行にη軸，これと直角にξ軸をとり，円弧の中心M点を原点に行程線をY軸，これを直角にX軸をとる。回転するx軸と固定されたξ軸とのなす角をθとすればθはカムの回転角となる。

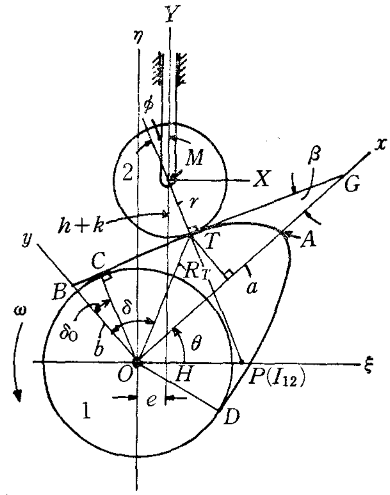

図1　往復円弧従動節をもつ正放物線カム

3.1　放物線カムと基礎円半径

放物線カムを図2に示す。放物線とx，y軸の交点をA，Bとし，基礎円との接点をC，Dとし，$OA=a$，$OB=b$，$OC=R_0$，$\angle BOC=\delta_0$ とす。R_0は基礎円の半径であり，カムの放物線は CAD である。放物線上に接触点Tをとり，$\angle TOB=\delta$，$OT=R_T$ で示し，放物線の方程式とT点のx y座標 x_T，y_T をδをパラメーターとして示せば次式が得られる。

$$a y_T^2=b^2(a-x_T) \quad \cdots\cdots(1)$$

$$x_T=R_T\sin\delta,\qquad y_T=R_T\cos\delta \quad \cdots\cdots(2)$$

式(2)を式(1)に代入すれば

$$a\cos^2\delta R_T^2+b^2\sin\delta R_T-ab^2=0 \quad \cdots\cdots(3)$$

となるので，これからR_Tを求めれば吟味の結果次式が得られる。

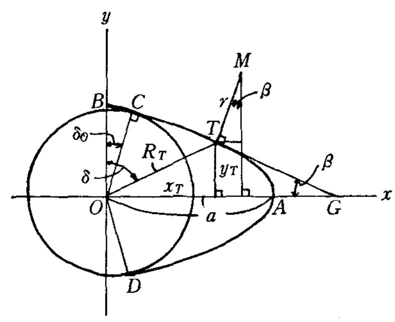

図2　放物線カム

$$R_T=b\times\frac{-b\sin\delta+\sqrt{b^2\sin^2\delta+4a^2\cos^2\delta}}{2a\cos^2\delta} \quad \cdots\cdots(4)$$

しかしこの式には分母に $\cos\delta$ があるので，$\delta=90°$ のとき R_T が不定となる。そこで式(4)のルートの中をKとおき，$\cos^2\delta=(K-b^2\sin^2\delta)/4a^2$ を式(3)に代入して変形すれば次式が得られる。

$$R_T=\frac{2ab}{\sqrt{4a^2\cos^2\delta+b^2\sin^2\delta}+b\sin\delta} \quad \cdots\cdots(5)$$

次に図2において接触点における接線がx軸となす角をβとすれば，βは式(1)を微分して次のように求められる。

$$\frac{dy}{dx}=-\frac{b^2}{2ay_T}=-\tan\beta \quad \cdots\cdots(6)$$

接触点Tが点Cにあるときは$\delta=\delta_0$，$R_T=R_0$，$\beta=\delta_0$となるので，$y_T=R_0\cos\delta_0$となり，これらを式(6)に代入すれば

$$\sin\delta_0=\frac{b^2}{2aR_0},\qquad \cos\delta_0=\frac{\sqrt{4a^2R_0^2-b^4}}{2aR_0} \quad\cdots\cdots(7)$$

が得られ，式(7)を式(5)に代入してR_0を求めればR_0は次式のようになる。

$$R_0=\frac{b\sqrt{4a^2-b^2}}{2a} \quad\cdots\cdots(8)$$

これからbを計算し，吟味の結果

$$b=\sqrt{2a(a-\sqrt{a^2-R_0^2})} \quad\cdots\cdots(9)$$

となり，a，R_0が与えられればbが求まる。

式(8)，(9)を式(7)に代入すればδ_0は次式で求まる。

$$\sin\delta_0=\frac{b}{\sqrt{4a^2-b^2}}=\frac{a-\sqrt{a^2-R_0^2}}{R_0} \quad\cdots\cdots(10)$$

3．2　従動節の円弧の中心座標と変位

従動節の円弧の中心Mのx y座標x_M，y_Mを求める。図2において従動節の円弧は放物線にT点で接触しているので，$\angle MTG=90°$となり，M点よりx軸に垂線MKを下せば，$\angle TMK=\beta$となるので次式が得られる。

$$x_M=x_T+r\sin\beta,\qquad y_M=y_T+r\cos\beta \quad\cdots\cdots(11)$$

式(6)より，$\sin\beta$，$\cos\beta$を求めれば

$$\sin\beta=\frac{b^2}{\sqrt{A}},\qquad \cos\beta=\frac{2ay_T}{\sqrt{A}},\qquad A=b^4+4a^2y_T^2 \quad\cdots\cdots(12),\ (13)$$

が得られるので，これを式(11)に代入すればx_M，y_Mは次式のようになる。

$$x_M=x_T+\frac{b^2r}{\sqrt{A}},\qquad y_M=y_T\left(1+\frac{2ar}{\sqrt{A}}\right) \quad\cdots\cdots(14)$$

次に図1において円弧の中心Mからξ軸に垂MHを下せば$MH=h+k$で，kはξ軸へのM点の最も低い高さで，hは従動節の変位である。M点のξ η座標をξ_M，η_Mとすれば$\xi_M=OH=e$，$\eta_M=MH=h+k$だからx_M，y_Mをξ η座標にθを用いて座標変換すれば次式のようになる。

$$\xi_M=x_M\cos\theta-y_M\sin\theta=e \quad\cdots\cdots(15)$$

$$\eta_M=x_M\sin\theta+y_M\cos\theta=h+k,\qquad k=\sqrt{(R_0+r)^2-e^2} \quad\cdots\cdots(16),\ (17)$$

式(15)より未定係数法でθを求めれば次のようになる。

$$\theta=\sin^{-1}\sqrt{1-\frac{e^2}{x_M^2+y_M^2}}-\varepsilon,\qquad \varepsilon=\tan^{-1}\frac{y_M}{x_M} \quad\cdots\cdots(18)$$

また式(15)をθで微分し，式(16)を代入すれば次式が得られる。

$$\eta_M=\frac{dx_M}{d\theta}\cos\theta-\frac{dy_M}{d\theta}\sin\theta \quad\cdots\cdots(19)$$

よって従動節の変位hは式(16)から次式で示される。

$$h=\eta_M-k=x_M\sin\theta+y_M\cos\theta-\sqrt{(R_0+r)^2-e^2} \quad\cdots\cdots(20)$$

3．3 往きと戻り行程のカムの回転角とリフト

図1と図3において往き行程の始点 C が従動節と接触するときのカムの回転角 θ を θ_c とすれば ΔMOH から次式のようになる。

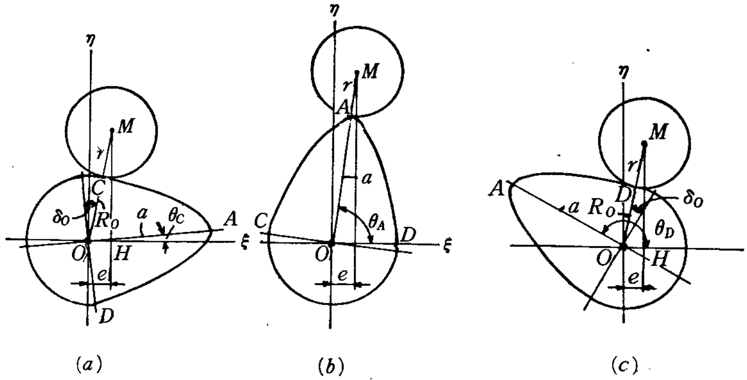

図3 行程の始点と終点における接触

$$\theta_c=\cos^{-1}\frac{e}{R_0+r}-(90°-\delta_0),\quad \overline{MH}=k \tag{21}$$

次に $\delta=90°$ すなわち往き行程の終点（放物線の頂点 A が従動節と接する場合）のカムの回転角を θ_A とすれば次式が得られる。

$$\theta_A=\cos^{-1}\frac{e}{a+r},\quad \overline{MH}=\sqrt{(a+r)^2-e^2} \tag{22}$$

戻り行程の終点 D が従動節に接する場合のカムの回転角 θ_D は次式のようになる。

$$\theta_D=\cos^{-1}\frac{e}{R_0+r}+(90°-\delta_0),\quad \overline{MH}=k \tag{23}$$

従動節の往き行程と戻り行程のカムの回転角をそれぞれ θ_o，θ_r とすれば次式が得られる。

$$\theta_o=\theta_A-\theta_c=\cos^{-1}\frac{e}{a+r}-\cos^{-1}\frac{e}{R_0+r}+(90°-\delta_0) \tag{24}$$

$$\theta_r=\theta_D-\theta_A=\cos^{-1}\frac{e}{R_0+r}-\cos^{-1}\frac{e}{a+r}+(90°-\delta_0) \tag{25}$$

また従動節のリフトを H とすれば式(22)，(17)から次式で表わされる。

$$H=\sqrt{(a+r)^2-e^2}-\sqrt{(R_0+r)^2-e^2} \tag{26}$$

3．4 従動節の速度

従動節の速度 $v=dh/dt=\omega\, dh/d\theta$ から速度は式(20)を θ で微分して得られるが，そのためには R_T，x_T，y_T，x_M，y_M，δ をあらかじめ θ で微分しておく必要がある。

式(3)を θ で微分し，それに式(3)を代入すれば次式が得られる。

$$\frac{dR_T}{d\theta}=B\frac{d\delta}{d\theta},\quad B=\frac{R_T^2(2aR_T\sin\delta-b^2)\cos\delta}{b^2(2a-R_T\sin\delta)} \tag{27}$$

式(2)と式(14)を θ で微分すれば次式が得られる。

$$\frac{dx_T}{d\theta}=M\frac{d\delta}{d\theta},\quad M=B\sin\delta+R_T\cos\delta \tag{28}$$

$$\frac{dy_T}{d\theta}=N\frac{d\delta}{d\theta},\quad N=B\cos\delta-R_T\sin\delta \tag{29}$$

$$\frac{dx_M}{d\theta}=C\frac{d\delta}{d\theta},\qquad C=M-\frac{4a^2b^2r\,y_T}{A^{3/2}}N \quad\cdots\cdots(30)$$

$$\frac{dy_M}{d\theta}=D\frac{d\delta}{d\theta},\qquad D=N\left(1+\frac{2ab^4r}{A^{3/2}}\right) \quad\cdots\cdots(31)$$

次に $d\delta/d\theta$ を求めるには式(30)，(31)を式(19)に代入して次式のように求められる。

$$\frac{d\delta}{d\theta}=\frac{\eta_M}{L},\qquad L=C\cos\theta-D\sin\theta \quad\cdots\cdots(32)$$

この式より式(27)～(31)の値が求まるので，式(20)を θ で微分して $dh/d\theta$ は次式のようになる。

$$\frac{dh}{d\theta}=\frac{d\eta_M}{d\theta}=\frac{dx_M}{d\theta}\sin\theta+\frac{dy_M}{d\theta}\cos\theta+e \quad\cdots\cdots(33)$$

3．5 従動節の加速度

従動節の加速度は $a=\omega^2d^2h/d\theta^2$ であるので，加速度は式(33)を θ で微分して求められるが，そのためには B, C, D，$d\delta/d\theta$，$dx_M/d\theta$，$dy_M/d\theta$ を θ で微分する必要がある。

式(27)～(31)を θ で微分すれば次式が得られる。

$$\frac{dB}{d\theta}=\left[\frac{2R_T\{aR_T(3B\sin\delta+R_T\cos\delta)-b^2B\}\cos\delta}{b^2(2a-R_T\sin\delta)}-\frac{R_T^2(2aR_T\sin\delta-b^2)\sin\delta}{b^2(2a-R_T\sin\delta)}+\frac{R_T^2(2aR_T\sin\delta-b^2)M}{b^2(2a-R_T\sin\delta)^2}\right]\frac{d\delta}{d\theta} \quad\cdots\cdots(34)$$

$$\frac{dC}{d\theta}=\frac{dB}{d\theta}\sin\delta+\frac{dR_T}{d\theta}\cos\delta+\left(N+\frac{4a^2b^2r}{A^{3/2}}y_TM\right)\frac{d\delta}{d\theta}+\frac{4a^2b^2r}{A^{5/2}}\left[\left(R_T\frac{dy_T}{d\theta}+y_T\frac{dR_T}{d\theta}\right)A\sin\delta-\left(B\frac{dy_T}{d\theta}+y_T\frac{dB}{d\theta}\right)A\cos\delta+12a^2y_T{}^2N\frac{dy_T}{d\theta}\right] \quad\cdots\cdots(35)$$

$$\frac{dD}{d\theta}=-\frac{24a^3b^4r\,y_TN}{A^{5/2}}\cdot\frac{dy_T}{d\theta}+\left(1+\frac{2ab^4r}{A^{3/2}}\right)\left(\frac{dB}{d\theta}\cos\delta-\frac{dR_T}{d\theta}\sin\delta-M\frac{d\delta}{d\theta}\right) \quad\cdots\cdots(36)$$

式(30)，(31)，(32)を θ で，微分すれば次式が得られる。

$$\frac{d^2\delta}{d\theta^2}=\frac{\frac{d\eta_M}{d\theta}}{L}+\frac{\eta_M\left(\frac{dD}{d\theta}\sin\theta-\frac{dC}{d\theta}\cos\theta+C\sin\theta+D\cos\theta\right)}{L^2} \quad\cdots\cdots(37)$$

$$\frac{d^2x_M}{d\theta^2}=\frac{dC}{d\theta}\,\frac{d\delta}{d\theta}+C\frac{d^2\delta}{d\theta^2} \quad\cdots\cdots(38)$$

$$\frac{d^2y_M}{d\theta^2}=\frac{dD}{d\theta}\,\frac{d\delta}{d\theta}+D\frac{d^2\delta}{d\theta^2} \quad\cdots\cdots(39)$$

式(33)を θ で微分すれば $d^2h/d\theta^2$ は次式のようになる。

$$\frac{d^2h}{d\theta^2}=\frac{d^2x_M}{d\theta^2}\sin\theta+\frac{d^2y_M}{d\theta^2}\cos\theta+\eta_M \quad\cdots\cdots(40)$$

以上の計算により，従動節の加速度を求めることができる。

3.6 往き行程の始点と終点の加速度

往き行程の始点Cにおいては$\delta=\delta_0$で式(10)で求められるので，それらを以上の式に代入して$d^2h/d\theta^2$を求める計算は非常に複雑で困難であるが，$e=0$の場合は次式で表わされる。

$$\text{始点}\quad \delta=\delta_0,\ \frac{d^2h}{d\theta^2}=\frac{2(R_0+r)(2a^2-b^2)\sqrt{4a^2-b^2}}{(4a^2-b^2)^{3/2}+2abr},\ \text{ただし}e=0 \quad\cdots\cdots(41)$$

式(41)から明らかなように始点の$d^2h/d\theta^2$を零とすることはできない。

往き行程の終点すなわち戻り行程の始点Aにおける$d^2h/d\theta^2$は$\delta=90°$として以上の各式を計算すれば次式で表わせられる。

$$\text{終点}\quad \delta=90°,\ \frac{d^2h}{d\theta^2}=-\frac{(2a^2-b^2)(a+r)^2}{(b^2+2ar)\sqrt{(a+r)^2-e^2}} \quad\cdots\cdots(42)$$

§4 押進め角

図1において接触点Tの法線とY軸のなす角をϕとすればϕは押進め角である。法線とξ軸の交点をPとすれば，Pは瞬間中心I_{12}であるので$\overline{OP}=dh/d\theta$となり，図から

$$\tan\phi=\frac{dh/d\theta-e}{h+k},\quad k=\sqrt{(R_0+r)^2-e^2} \quad\cdots\cdots(43)$$

が得られる。

往き行程の始点Cにおける押進め角をϕ_Cとすれば，始点においては$dh/d\theta=0$，$h=0$だから式(43)より次式が得られる。

$$\tan\phi_c=\frac{-e}{\sqrt{(R_0+r)^2-e^2}} \quad\cdots\cdots(44)$$

§5 カムの曲率半径と滑り率

カムの滑り率を求めるには図1の$\overline{TP}$の長さとカムの曲率半径を求める必要がある。図から$\overline{TP}$は次式のようになる。

$$\overline{TP}=\sqrt{\eta_M^2+(dh/d\theta-e)^2}-r \quad\cdots\cdots(45)$$

次にx y座標における曲線の曲率半径ρは次式で与えられる。

$$\rho=\frac{\{1+(dy/dx)^2\}^{3/2}}{d^2y/dx^2} \quad\cdots\cdots(46)$$

5.1 曲率半径

式(1)をxで2回微分して式(46)に代入すれば放物線カムの接触点Tの曲率半径ρ_Tは次式のようになる。

$$\rho_T=\frac{(4a^2R_T^2\cos^2\delta+b^4)^{3/2}}{2ab^4} \quad\cdots\cdots(47)$$

往き行程の始点Cと終点Aの曲率半径は$\delta=\delta_0$，$\delta=90°$から式(7)を用いて次式のようになる。

$$\delta=\delta_0,\ \rho_T=\frac{4a^2R_0^3}{b^4}=\frac{(4a^2-b^2)^{3/2}}{2ab},\quad \delta=90°,\ \rho_T=\frac{b^2}{2a} \quad\cdots\cdots(48)$$

5.2 滑り率

カムと従動節の滑り率をσ_1，σ_2とすれば前報[1)]により次式で示される。

$$\sigma_1=\frac{\rho_T+r}{\rho_T}\cdot\frac{\overline{TP}}{r+\overline{TP}},\quad \sigma_2=\frac{\rho_T+r}{r}\cdot\frac{\overline{TP}}{\rho_T-\overline{TP}} \quad\cdots\cdots(49)$$

往き行程の始点Cでは $\overline{TP}=R_0$，終点Aでは$\overline{TP}=a$ となるので，これらを式(48)，(49)に代入すればカムの始点と終点の滑り率 σ_{1C}，σ_{1A} は次式のようになる。

$$\sigma_{1C}=\frac{4a^2R_0^3+b^4r}{4a^2R_0^2(R_0+r)},\quad \sigma_{1A}=\frac{a(b^2+2ar)}{b^2(a+r)} \quad\cdots\cdots(50),\ (51)$$

§６ 計　算　例

今まで述べてきた項目について，それぞれに必要な値を与えて計算し，各項目の性質について調べる。

まず最初に $e=0$，$H=1$，$R_0=1.5$，$a=2.5$ の場合の押進め角ϕを $r=0$〜5 の時の値で式(43)から求めたものを図４に示す。$e=0$ の場合往き行程と戻り行程でϕが同じだから $\delta=0°$〜90° において示す。図においてrが小さい程最大押進め角 ϕ_{max} は減少し，$r=0$ のとき ϕ_{max} が最大となることがわかる。

次に $r=0$ の場合 $e=0$，$H=1$ において $R_0=0.5$〜3.0 に変化させたときの a，b，δ_0 を求めたものを表１に示し，それらのデータで $\delta=0°$〜90° の押進め角ϕを求めたものを図５に示す。

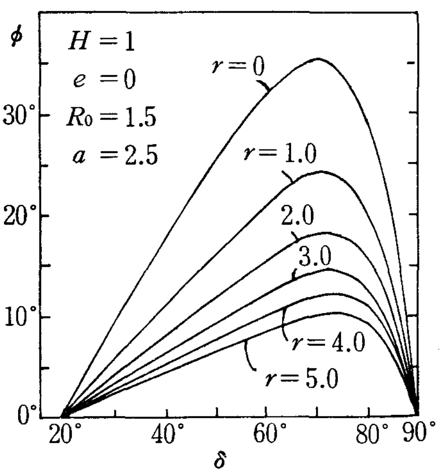

図４　$e=0$，$H=1$ の場合の各rに対する押進め角ϕ

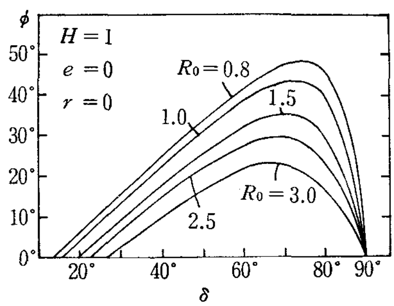

図５　ナイフエッジの場合の各R_0の押進め角

表１　$e=0$，　$H=1$，　$r=0$

R_0	0.5	0.8	1.0	1.5	2.0	2.5	3.0
a	1.5	1.8	2.0	2.5	3.0	3.5	4.0
b	0.50731	0.82169	1.03528	1.58114	2.14093	2.71175	3.29150
$\delta_0°$	9.87928	13.55835	15.54227	19.47122	22.45552	24.84747	26.83458
$\alpha°$	80.12072	76.44165	74.45773	70.52877	67.54448	65.15253	63.165416
$\phi°_{max}$	58.68389	48.70207	43.83039	35.26439	29.68745	25.75668	22.82688
$\delta°$	78.3110	74.8110	73.1521	70.5311	69.0341	68.1271	67.5571

図から R_0 が増すにつれて ϕ_{max} が減少することがわかる。$\phi_{max}<30°$ にするためには $R_0>2$，$a>3$ とせねばならぬので，カムを小さくするには $r>0$ とせねばならぬ。ϕ_{max} のときδを表１に示す。

さらに図6は$e=0$, $H=1$, $R_0=1$, $a=2$, $b=1.03528$の条件を与え，$r=0.1$, 1.0, 5.0の場合の$d^2h/d\theta^2$, ϕ, σ_1 を示す。$d^2h/d\theta^2$ について言えば r が小さい程始点の $d^2h/d\theta^2$ は小さいが終点の $d^2h/d\theta^2$ は非常に大きくなる。σ_1 の方は r が大きい程終点の σ_{1A} が非常に大きくなるので r は小さくも大きくもできない。

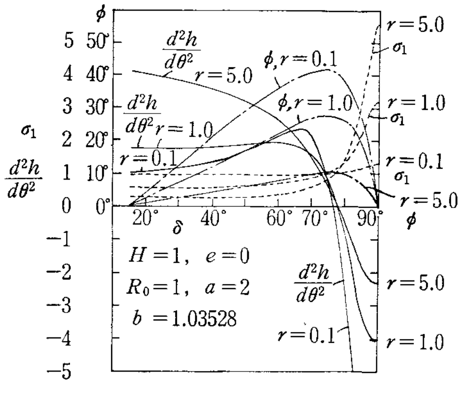

図6　r の変化による $d^2h/d\theta^2$, ϕ, σ_1

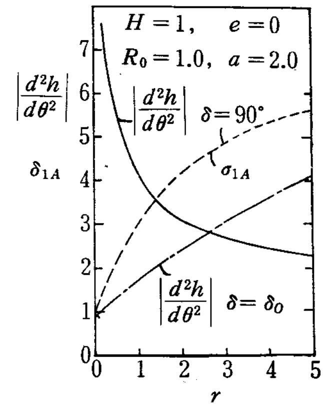

図7　r の変化による始点と終点の $d^2h/d\theta^2$ と σ_{1A}

図7に $e=0$, $H=1$, $R_0=1$, $a=2$ の場合の $r=0\sim5$ の往き行程の始点と終点の $d^2h/d\theta^2$ とカムの最大滑り率 σ_{1A} を式(41), (42), (51) より求めたものを示す。図から r が小さいときは終点の $d^2h/d\theta^2$ が急激に大となり，始点のそれは小さく，r の増すにつれ，両方の絶対値は等しくなり，r が大きいと逆に始点の $d^2h/d\theta^2$ が大となる。σ_{1A} は r の増加と共に増すが，両方の $d^2h/d\theta^2$ が等しい $r\fallingdotseq2.8$ においては $\sigma_{1A}\fallingdotseq4.6$ となるので使用できる。

§7　作用角αの指定　$e=0$

往き行程と戻り行程のカムの回転角を指定するためには式(24), (25) の θ_o, θ_r を指定する必要がある。$e\fallingdotseq0$ の場合はこれらを指定することは困難であるが $e=0$ のときは $\theta_o=\theta_r=90°-\delta_0=\alpha$ となるので，αを指定すれば式(7)より $\cos\alpha=b^2/2aR_0$ となり，これに $a=H+R_0$ と式(9)を代入して R_0 を求めれば

$$R_0=\frac{2H\cos\alpha}{(1-\cos\alpha)^2} \quad\cdots\cdots(52)$$

が得られるので，これから a, b が次式のように求められる。

$$a=\frac{H(1+\cos^2\alpha)}{(1-\cos\alpha)^2},\quad b=\frac{2H\cos\alpha\sqrt{1+\cos^2\alpha}}{(1-\cos\alpha)^2} \quad\cdots\cdots(53),\ (54)$$

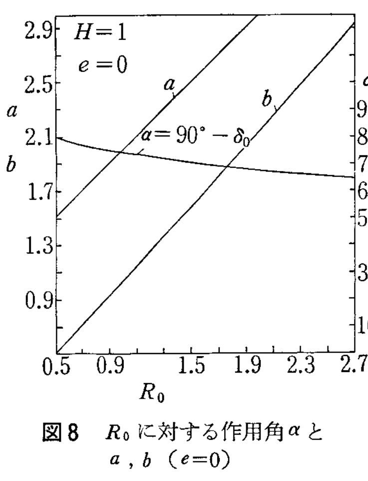

図8　R_0 に対する作用角αと a, b ($e=0$)

図8は$e=0$, $H=1$ の場合の $R_0=0.5\sim2.7$ のαと a, bを求めたもので，αは R_0 が増加すれば減少するが，その範囲は60°〜80° である。R_0 に対し a は直線的に，b もほぼ直線的に増加する。

§8　始点の押進め角とリフトの指定

図4，5より R_0 および r が小さい場合 ϕ_{max} が非常に大きくなるので，これを小さくするためには往き行程の始点の押進め角ϕ_C を負にする必要がある。式(44)から $\tan\phi_C=-\mu$ とすれば

$$\tan(-\phi_C)=\mu=\frac{e}{\sqrt{(R_0+r)^2-e^2}} \quad\cdots\cdots(55)$$

が得られるので，この式を変形して r を求めれば次式が得られる。

$$r=e\frac{\sqrt{1+\mu^2}}{\mu}-R_0 \quad \cdots\cdots(56)$$

次に従動節のリフトは式(26)で示されるので，これを変形すれば

$$H^2+R_0{}^2-a^2-2(a-R_0)r+2H\sqrt{(R_0+r)^2-e^2}=0 \quad \cdots\cdots(57)$$

となり，この式に式(55)，(56)を代入して e を求めれば

$$e=\frac{\mu\{H^2-(a-R_0)^2\}}{2\{(a-R_0)\sqrt{1+\mu^2}-H\}} \quad \cdots\cdots(58)$$

が得られる。これを式(56)に代入すれば r は次式のようになる。

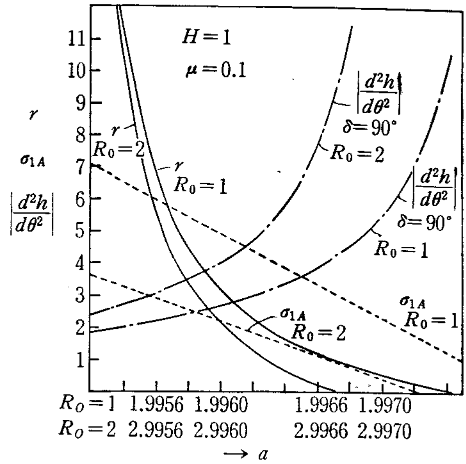

図9　$R_0=1$，2 の場合の各 a に対する r と終点のσ_{1A} と $|d^2h/d\theta^2|$

$$r=\frac{\sqrt{1+\mu^2}(a^2-R_0{}^2-H^2)-2HR_0}{2H-2(a-R_0)\sqrt{1+\mu^2}} \quad \cdots\cdots(59)$$

式(58)から e が正であるためには分母，分子を正とすれば次式が得られる。

$$H>(a-R_0)>\frac{H}{\sqrt{1+\mu^2}} \quad \cdots\cdots(60)$$

μ の値は小さいので $a-R_0$ の範囲は非常に小さい。例えば $H=1$，$\mu=0.1$ のとき $1>(a-R_0)>0.9950972$，$H=1$，$\mu=0.2$ のとき $1>(a-R_0)>0.9806806$

図9は $H=1$，$\mu=0.1$，($R_0=1$，$a=1.9952\sim1.9972$)，($R_0=2$，$a=2.9952\sim2.9968$) の場合において式(58)，(59)，(9)から，それぞれ e，r，b を求め，式(42)から終点の $|d^2h/d\theta^2|$，式(51)から終点のカムの滑り率 σ_{1A} を求めたものを示した。図から同じ σ_{1A} のとき $R_0=1$ の方が $R_0=2$ よりも終点の加速度が大きい。r は逆に小さくなる。故に a を大きくすれば σ_{1A} は小さくなるが，終点の加速度が大と

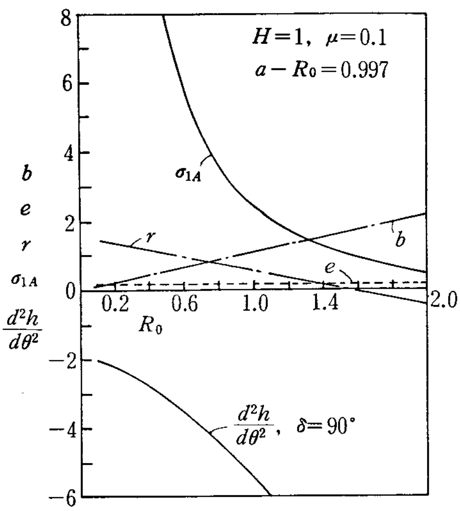

図10　R_0 に対する b，e，r，σ_{1A}，$d^2h/d\theta^2(\delta=90°)$

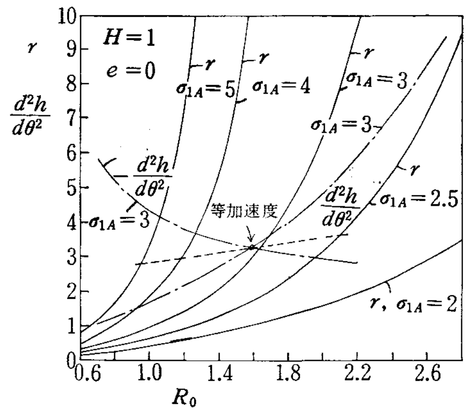

図11　σ_{1A} を指定し，各 R_0 に対する r と $\sigma_{1A}=3$ の場合の始点と終点の $d^2h/d\theta^2$

なるので，σ_{1A} を許せるだけ大きくして，r を大にして $|d^2h/d\theta^2|$ を小さくせねばならぬ。

図10は $H=1$，$\mu=0.1$，$a-R_0=0.997$ の場合の R_0 の影響を調べるために $R_0=0.2\sim2.0$ の場合の r，b，e，σ_{1A}，$d^2h/d\theta^2(\delta=90°)$ を示す。図から $\sigma_{1A}<5$ にするためには $R_0>0.6$ でなければならず，また R_0 を大きくすると r が負となり，$d^2h/d\theta^2(\delta=90°)$ が非常に大きくなる。

§9　カムの最大滑り率の指定

図6よりカムの滑り率 σ_1 は $e=0$ の場合 $\delta=90°$ で最大となり $e>0$ の場合はそれを少し過ぎた所で最大となると思われるが，計算の都合上終点 A の σ_{1A} を近似的最大滑り率 σ_{1max} として，これを指定したい。式(9)を式(51)に代入すれば

$$\sigma_{1A}=\frac{a(a+r-\sqrt{a^2-R_0^2})}{(a+r)(a-\sqrt{a^2-R_0^2})} \quad\cdots\cdots(61)$$

が得られる。さらに式(59)の r をこれに代入し，R_0，σ_{1A} を指定すれば a が求められるはずだが，これは a の6次式となって困難なので式(61)から r を求めれば次式のようになる。

$$r=\frac{a(a-\sqrt{a^2-R_0^2})(\sigma_{1A}-1)}{a-(a-\sqrt{a^2-R_0^2})\sigma_{1A}} \quad\cdots\cdots(62)$$

9．1　$e=0$ の場合の σ_{1max} の指定

$e=0$ の場合は $a=H+R_0$ で $\sigma_{1A}=\sigma_{1max}$ となるのでこれを式(62)に代入すれば次式のようになる。

$$r=\frac{(H+R_0)(H+R_0-\sqrt{H(H+2R_0)})(\sigma_{1A}-1)}{H+R_0-(H+R_0-\sqrt{H(H+2R_0)})\sigma_{1A}} \quad\cdots\cdots(63)$$

図11は $H=1$，$e=0$ において $\sigma_{1A}=2.0\sim5.0$ を指定し，$R_0=0.6\sim2.8$ の場合の r，$|d^2h/d\theta^2|\delta=90°$ を式(63)，(42)から求めたもので，σ_{1A} を小さくするためには r を小さくし，R_0 を大きくすればよい。また R_0 を小さくすると終点の $|d^2h/d\theta^2|$ が大となる。図中の一点鎖線は $\sigma_{1A}=3.0$ の場合の始点の $d^2h/d\theta^2$ $(\delta=\delta_0)$ を式(41)より示す。これから R_0 を大にすれば始点の $d^2h/d\theta^2$ が大きくなるので，R_0 には適当な範囲がある。また破線は始点と終点の $d^2h/d\theta^2$ の絶対値が等しい場合の $d^2h/d\theta^2$ を示す。この等加速度の場合は R_0 を小さくする程 $|d^2h/d\theta^2|$ が小となることがわかる。

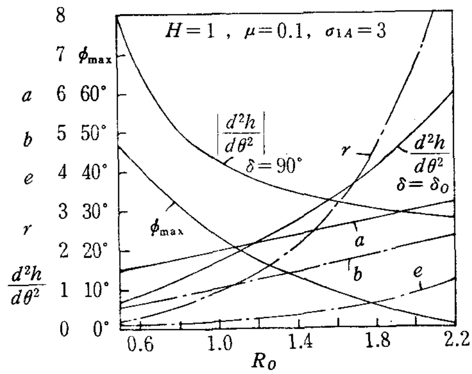

図12　μ，σ_{1A} を指定し，各 R_0 に対する a，b，e，r と始点と終点の $d^2h/d\theta^2$

9．2　$e>0$ の場合の σ_{1A} の指定

$e>0$ の場合 H，μ，σ_{1A}，R_0 を指定した場合は，a を任意に与え，式(58)より e，式(59)より r，式(9)より b を求め，式(51)より σ_{1A} を求め，σ_{1A} が指定された値になるまで繰返し計算し，そのときの a を求め，b，e，r と始点と終点の $|d^2h/d\theta^2|$ を求め，例えば $H=1$，$\mu=0.1$，$\sigma_{1A}=3$ の場合，$R_0=0.5\sim2.2$ としたときのそれらを表2と図12に示す。

表２　$H=1,\quad \mu=0.1,\quad \sigma_{1A}=3$

	R_0	0.5	0.6	0.8	1.0	1.5	1.56	2.0
	a	1.49794	1.59764	1.79714	1.99674	2.49602	2.55596	2.99555
	b	0.50733	0.61129	0.82177	1.03541	1.58145	1.64799	2.14148
	e	0.07040	0.09019	0.13525	0.19036	0.40266	0.43743	0.86342
	r	0.20752	0.30637	0.55926	0.91307	2.54669	2.83614	6.67724
始点	$\frac{d^2h}{d\theta^2}$	0.68170	0.85961	1.24278	1.67391	3.03783	3.22550	4.99860
終点	$\frac{d^2h}{d\theta^2}$	−8.21400	−6.66735	−5.08379	−4.26548	−3.31154	−3.25274	−2.90992
	ϕ°_{max}	47.952°	41.772°	31.855°	24.136°	20.955°	9.836°	2.767°

図において R_0 が大きい程 a，b，r も大となり，始点の $d^2h/d\theta^2$ は増大し，終点の $|d^2h/d\theta^2|$ は減少する。途中両者が等しくなる場合 $R_0 \doteqdot 1.56$ が存在する。図中に ϕ_{max} の線を示すが，$R_0<0.8$では $\phi_{max}>30^\circ$ となる。

図13は表２の $R_0=1.0$ の場合の h，$dh/d\theta$，$d^2h/d\theta^2$，ϕ，σ_1を回転角 θ に対して示し，図14は表２の$R_0=1.56$ の場合を δ に対して示したもので，ϕ がかなり小さくなることがわかる。

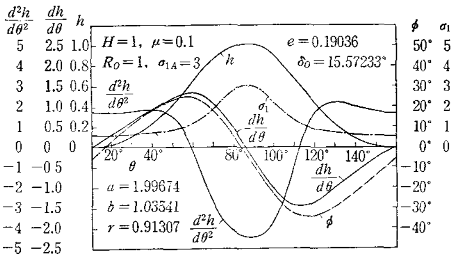

図13　H，μ，σ_{1A}，R_0 を指定したときの運動と ϕ

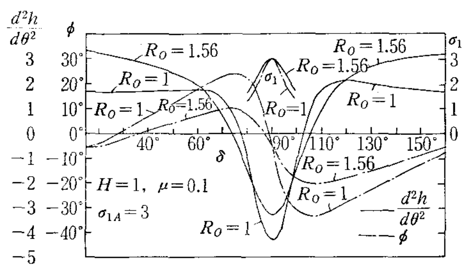

図14　$\mu=0.1$，$\sigma_{1A}=3$，$R_0=0$，1.56 の ϕ，$d^2h/d\theta^2$，σ_1

§10　往き行程の始点と終点の等加速度，$e=0$

図12から往き行程の始点と終点の $|d^2h/d\theta^2|$ が一致する等加速度の場合が存在することがわかる。式(41)，(42)の絶対値を等しいとおき r を求めれば次の２次式を得る。ただし $e=0$ の場合である。

$$2a^2(b-2\sqrt{4a^2-b^2})r^2+a\{-6a^2b+2b^3+\sqrt{4a^2-b^2}(4a^2-3b^2)\}r+(4a^2-b^2)(a^2\sqrt{4a^2-b^2}-b^3)=0$$

これから吟味の結果 r は次式のようになる。

$$r=\frac{6a^2b-2b^3+\sqrt{4a^2-b^2}(3b^2-4a^2)-\sqrt{D}}{4a(b-2\sqrt{4a^2-b^2})} \quad \cdots\cdots(64)$$

$$D=320a^6-13b^6+84a^2b^4-204a^4b^2-4b\sqrt{4a^2-b^2}(20a^4+a^2b^2-b^4)$$

よって，$e=0$，$H=1$，$R_0=0.5\sim3.0$ を与えて $a=H+R_0$，式(9)より b，式(64)から r を求め，これを式(41)により $|d^2h/d\theta^2|$，式(51)より σ_{1A} を求めて表３と図15に示す。図から R_0 を小さくすれば $|d^2h/d\theta^2|$ は小さくなるが σ_{1A} が非常に大きくなる。$\sigma_{1A}<5$ とするには $R_0=1.0\sim2.0$ の範囲が良い。図11から $\sigma_{1A}=3$ の場合 $R_0\doteqdot1.56$ となる。表３にこの場合のデータを示す。

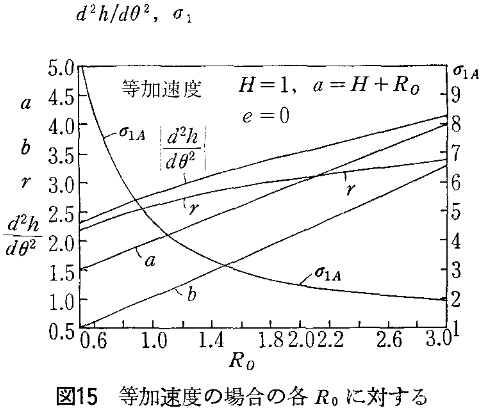

図15　等加速度の場合の各 R_0 に対する a，r，b，σ_{1A}と $|d^2h/d\theta^2|$ $(e=0)$

表3 $e=0$, $H=1$ 始点と終点の等加速度

R_0	a	b	r	$\lvert d^2h/d\theta^2 \rvert$	σ_{1A}	$\delta_0°$
0.5	1.5	0.50731	2.17264	2.29979	10.75	9.87928
0.75	1.75	0.76877	2.38226	2.56110	6.40	13.01159
1.0	2.0	1.03528	2.56155	2.79231	4.63	15.54227
1.5	2.5	1.58114	2.85153	3.19349	3.13	19.47122
2.0	3.0	2.14093	3.07273	3.53929	2.48	22.45552
2.5	3.5	2.71175	3.24209	3.84724	2.12	24.84747
3.0	4.0	3.29150	3.37038	4.12735	1.89	26.83458

図16は表3の$R_0=1.0$, 1.5, 2.0の場合のϕ, σ_1, $d^2h/d\theta^2$を$\delta=0°$～$90°$で示す。ϕ, σ_1について言えばR_0は大きい程良く，$d^2h/d\theta^2$ではR_0が小さい程よいが，$R_0=1.0$の場合$\phi_{max}\doteqdot 17.2°<20°$, $\sigma_{1A}\doteqdot 4.63<5$なので，$R_0=1.0$の場合は良好である。図17はこの場合の$h$, $dh/d\theta$, $d^2h/d\theta^2$をθで，図18はϕ, σ_1, σ_2をδで示したものである。図19はこの場合の従動節の滑り率σ_2を従動節の円弧上に示したもので戻り行程のσ_2の方が往き行程の場合よりも大きく，両端で$\sigma_2=\infty$となり，σ_2としては良好である。

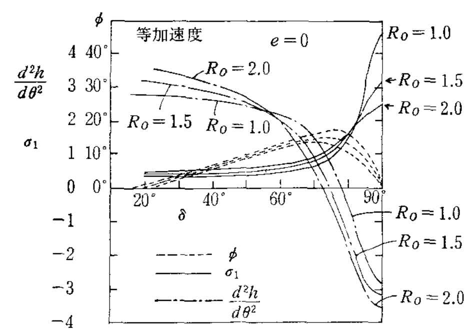

図16 等加速度の場合の$R_0=1$, 1.5, 2のときのϕ, σ_1, $d^2h/d\theta^2$

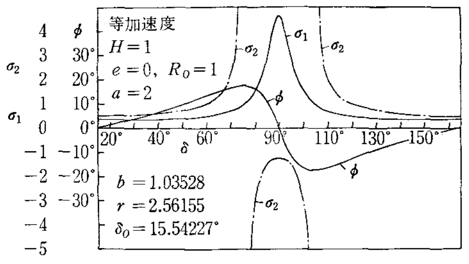

図18 等加速度の$R_0=1$のϕ, σ_1, σ_2

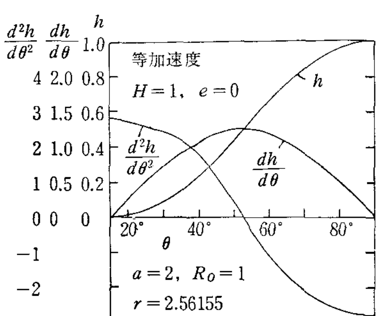

図17 等加速度の$R_0=1$の運動

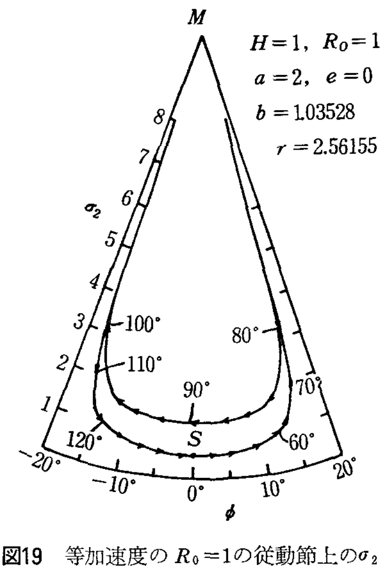

図19 等加速度の$R_0=1$の従動節上のσ_2

図20は $\sigma_{1A}=3$, $R_0=1.5763$ の場合の h, $dh/d\theta$, $d^2h/d\theta^2$, ϕ, σ_1 を示す。図21は円弧上の σ_2 を示す。良好である。

§11　カムの輪郭，ピッチ曲線と接触点の軌跡

カムの輪郭は x_T, y_T により求められるので式(2)より求まる。

ピッチ曲線は x_M, y_M から式(14)より求められ，接触点の軌跡は図1において T 点の $\xi\ \eta$ 座標を求めればよいので次式を得る。

$$\xi_T=x_T\cos\theta-y_T\sin\theta,\qquad \eta_T=x_T\sin\theta+y_T\cos\theta \quad\cdots\cdots(65)$$

図22，23はカムの輪郭，ピッチ曲線および接触点の軌跡を示す。

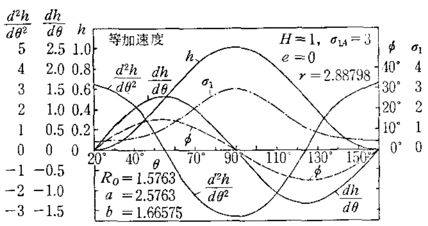

図20　等加速度，$\sigma_{1A}=3$, $R_0=1.5763$ の運動と ϕ, σ_1

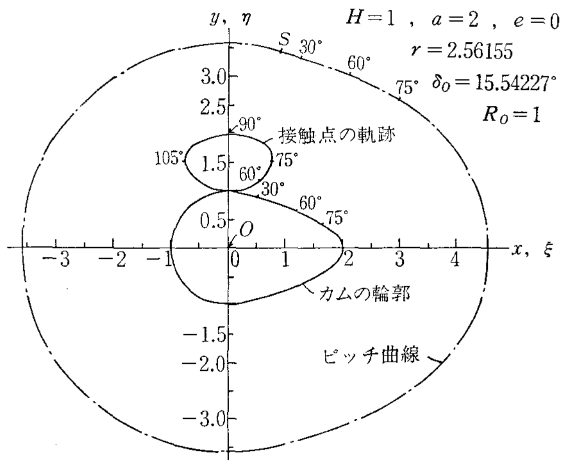

図22　図17の等加速度のカムの輪郭と接触点の軌跡

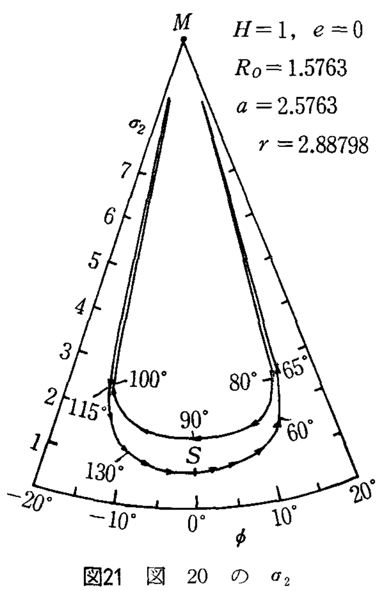

図21　図 20 の σ_2

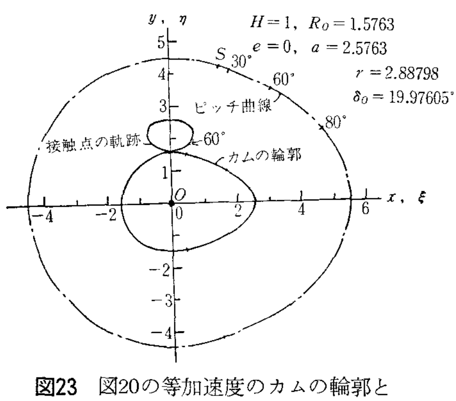

図23　図20の等加速度のカムの輪郭と接触点の軌跡

§12　結　　　論

以上の研究によって円弧従動節をもつ往復正放物線カムについて次の結論が得られた。

(1)　押進め角については同一のリフトに対し，R_0 か r を大きくすれば ϕ_{max} を小さくでき，さらに e すなわち μ を大きくする程 ϕ_{max} は小さくなる。(2)　カム最大滑り率 σ_{1max} は R_0 を大きくするか r を小さくすれば小さくなる。(3)　従動節の滑り率 σ_2 は従動節の接触面の両端で無限大となるが途中はほぼ

一定である。(4)　リフト，始点の押進め角，終点のカムの滑り率と基礎円の半径を指定して，カムの大きさおよび従動節の円弧半径，かたより量を計算することができる。(5)　加速度においては往き行程の始点と終点のどちらの加速度も零にすることはできないが，その絶対値を等しくなるようにカムの各寸法を選ぶことができる。ただしそのとき σ_{1max} を指定すれば基礎円の半径が決定できる。$H=1$ に対し，$e=0$ の場合 $R_0=1.5763$ が最良であることがわかる。

以上の研究において本校河野正来教官および本校学生日浦喜久，松本隆幸両君の協力を得た。

文　　献

1)　糸島寛典：往復偏心正楕円カムの研究（第1報）—円弧従動節—，呉高専研究報告，12—1，1976

（昭和52年5月31日受付）

揺動偏心正楕円カムの研究(第2報)

——平　板　従　動　節——

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Studies on the Eccentric Profile Cam with an Oscillating Follower (Report 2)

——Flat Plate Follower——

Hironori ITOSHIMA
Masaki KŌNO

The flat plate follower is oscillating on the elliptical profile of the cam and the pivot of the cam is offset from the center of the ellipse. The elliptical curve is expressed in xy coordinates on the cam.

In this paper, the angular motion of the oscillating follower is analysed, and the oscillating angle, the pressure angle, the angular acceleration and the specific sliding are examined.

If the oscillating angle, the specific sliding of the cam at the end point, the ratio of the angular accelerations at the starting point and the end point are specified, then each size of the best cam and the offset of the flat plate follower can be designed.

§1　緒　　言

前報[1]においてカムの輪郭が楕円形の楕円カムを偏心した点を軸として回転させ，円弧をもつ揺動従動節の場合の運動を論じた。

本報においては同じ偏心楕円カムと揺動平板従動節を組合せた場合の従動節の運動と最大角加速度，従動節の揺動角，滑り率を指定した場合のカムの寸法と偏心量と平板従動節のかたより量を求めて最適のカムの設計を行う。

§2　記　　号

a：楕円の長軸の半径	f：揺動平板従動節のかたより量
b：楕円の短軸の半径	d：カムと従動節の軸間距離
c：長軸上の偏心量	Ψ：従動節の揺動角
δ：楕円の長軸とATのなす角	φ_1：従動節がABとなす角
θ：長軸とABのなす角	φ_0：始点における従動節がABとなす角
θ_o：往き行程のカムの回転角	φ：従動節の角変位
θ_r：戻り行程のカムの回転角	ϕ：カムの押進め角
R_T：カムのラジアスベクトルAT	s：平板上の移動距離
ρ_T：カムの曲率半径	σ_2：従動節の滑り率

σ_1：カムの滑り率
ω_1：カムの角速度
ω_2：従動節の角速度
$d\varphi_1/d\theta$：従動節の角速度$=\omega_1 d\varphi_1/d\theta$
$d^2\varphi_1/d\theta^2$：従動節の角加速度$=\omega_1^2 d^2\varphi_1/d\theta^2$

§ 3 偏心楕円カムにおける平板従動節の運動

楕円カムの長径，短径をそれぞれ a，b とし，中心 O より長径に沿い c だけ偏心した A 点を軸として左回りにカムは回転しているものとする。f だけオフセットした平板従動節は B 点を軸として揺動している。AB の長さを d とし，A 点を原点とし長径を x 軸，それに直角に y 軸をカム上にとる。B 点を原点とし，従動節の接触面に平行に Y 軸をとり，これに直角に X 軸をとる。$\angle YBA=\varphi_1$ とすればこれは従動節の角変位を示す。

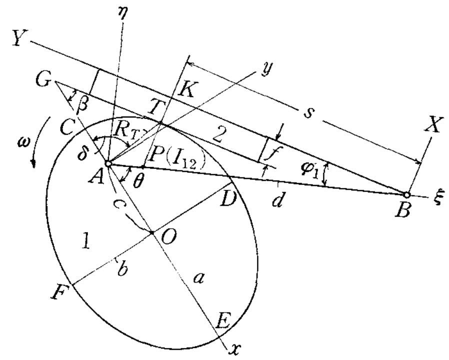


図1 揺動平板従動節をもつ偏心正楕円カム

長径と短径の両端をそれぞれ C，E と D，F とする。接触点 T において垂線を立て Y 軸との交点を K，AB との交点を P とすれば，P 点はカム1と従動節2の瞬間中心 I_{12} となる。BK の長さを s で示す。$AT=R_T$，$\angle CAT=\delta$，$\angle BAE=\theta$ とすれば θ はカムの回転角で，δ をパラメーターとして θ を求める。

xy 座標においてこの楕円の方程式を次式で示される。

$$\left(\frac{x_T-c}{a}\right)^2+\left(\frac{y_T}{b}\right)^2=1, \qquad b^2(x_T-c)^2+a^2y_T^2=a^2b^2 \quad \cdots\cdots(1)$$

$$x_T=-R_T\cos\delta, \qquad y_T=R_T\sin\delta \quad \cdots\cdots(2)$$

で示されるので，式(2)を式(1)に代入すれば R_T は次式のようになる。

$$R_T=b\times\frac{-bc\cos\delta+a\sqrt{A-c^2\sin^2\delta}}{A}, \qquad A=a^2\sin^2\delta+b^2\cos^2\delta \quad \cdots\cdots(3),\ (4)$$

δ を与えれば R_T が求まるので式(2)より x_T，y_T が求められる。次に接触点 T における接線が x 軸と交わる点を G とし，なす角を β とすれば式(1)を x で微分して次式で求められる。

$$\tan\beta=\frac{b^2(c-x_T)}{a^2y_T}=\frac{b^2(c+R_T\cos\delta)}{a^2R_T\sin\delta} \quad \cdots\cdots(5)$$

A 点より Y 軸に垂線 AL を下せば $\angle ABL=\theta-\beta$ となり，AL と接触面の交点を H とすれば $\angle ATH=180^\circ-(\beta+\delta)$ となるので

$$d\sin(\theta-\beta)=R_T\sin(\beta+\delta)+f$$

が得られるが，x 軸が AB より下にある θ を負で示すことにすれば θ は次式のようになる。

$$\theta=-\beta-\sin^{-1}\frac{R_T\sin(\beta+\delta)+f}{d} \quad \cdots\cdots(6)$$

3．1 従動節の角変位

カムの往き行程の始点 C で接触するときの φ_1 を φ_0 で示せば，φ_0 は従動節の角変位の最小値であって次式で示される。

$$\varphi_0=\sin^{-1}\frac{a-c+f}{d} \quad \cdots\cdots(7)$$

次に往き行程の終点Eが従動節と接触するときはΨを揺動角とすれば φ_1は$\varphi_0+\Psi$ となるので

$$\Psi+\varphi_0=\sin^{-1}\frac{a+c+f}{d} \qquad (8)$$

となり，揺動角Ψは次式で示される。

$$\Psi=\sin^{-1}\frac{a+c+f}{d}-\sin^{-1}\frac{a-c+f}{d} \qquad (9)$$

図1と式(6)より φ_1 は次式で求められる。

$$\varphi_1=-\theta-\beta=\sin^{-1}\frac{R_T\sin(\beta+\delta)+f}{d} \qquad (10)$$

これから従動節の角変位φは次式のようになる。

$$\varphi=\varphi_1-\varphi_0=\sin^{-1}\frac{R_T\sin(\beta+\delta)+f}{d}-\sin^{-1}\frac{a-c+f}{d} \qquad (11)$$

3.2　従動節の角速度　式(11)あるいは式(10)の角変位φあるいはφ_1を時間 t で微分すれば従動節の角速度が得られる。$d\varphi/dt=\omega_1\cdot d\varphi_1/d\theta$ となり，ω_1 はカムの角速度である。式(11)から R_T，β, δ を θ で微分する必要がある。式(4)の A を θ で微分すれば

$$\frac{dA}{d\theta}=B\frac{d\delta}{d\theta},\qquad B=2(a^2-b^2)\sin\delta\cos\delta \qquad (12),\ (13)$$

が得られる。同様に式(3)，(5)から次式が得られる。

$$\frac{dR_T}{d\theta}=E\frac{d\delta}{d\theta},\qquad E=\frac{b}{A}\left[bc\sin\delta+\frac{a(a^2-b^2-c^2)}{\sqrt{A-c^2\sin^2\delta}}\sin\delta\cos\delta-\frac{R_TB}{b}\right] \qquad (14),\ (15)$$

$$\frac{d\beta}{d\theta}=F\frac{d\delta}{d\theta},\qquad F=-a^2b^2\frac{R_T{}^2+c(E\sin\delta+R_T\cos\delta)}{a^4R_T{}^2\sin^2\delta+b^4(c+R_T\cos\delta)^2} \qquad (16),\ (17)$$

次に式(6)を θ で微分し，式(14)，(16)を代入すれば $d\delta/d\theta$ が次式のように求められる。

$$\frac{d\delta}{d\theta}=\frac{-d\cos(-\theta-\beta)}{K},\qquad K=Fd\cos(-\theta-\beta)+E\sin(\beta+\delta)+R_T(F+1)\cos(\beta+\delta) \qquad (18),\ (19)$$

よって式(10)あるいは式(11)を θ で微分して従動節の角速度は次式のように求められる。

$$\frac{d\varphi}{d\theta}=\frac{d\varphi_1}{d\theta}=\frac{1}{d\cos\varphi_1}\left[\frac{dR_T}{d\theta}\sin(\beta+\delta)+R_T\cos(\beta+\delta)(F+1)\frac{d\delta}{d\theta}\right] \qquad (20)$$

3.3　従動節の角加速度　従動節の角加速度は $d^2\varphi_1/dt^2=\omega_1{}^2d^2\varphi_1/d\theta^2$ で表わせるので，式(20)を θ で微分すればよい。それには式(13)〜(18)を θ で微分しておく必要がある。その結果

$$\frac{dB}{d\theta}=2(a^2-b^2)(\cos^2\delta-\sin^2\delta)\frac{d\delta}{d\theta} \qquad (21)$$

$$\frac{dE}{d\theta}=G\frac{d\delta}{d\theta},\qquad G=\frac{b}{A}\left[bc\cos\delta+a(a^2-b^2-c^2)\frac{-a^2\sin^4\delta+b^2\cos^4\delta+c^2\sin^4\delta}{(A-c^2\sin^2\delta)^{3/2}}-\frac{2BE}{b}-R_T\frac{2(a^2-b^2)(\cos^2\delta-\sin^2\delta)}{b}\right] \qquad (22),\ (23)$$

$$\frac{dF}{d\theta}=\frac{-a^2b^2}{a^4R_T{}^2\sin^2\delta+b^4(c+R_T\cos\delta)^2}\left[2R_T\frac{dR_T}{d\theta}+c\frac{dE}{d\theta}\sin\delta\right.$$

$$+2c\frac{dR_T}{d\theta}\cos\delta-cR_T\sin\delta\frac{d\delta}{d\theta}+\frac{F}{a^2b^2}\left\{2a^4R_T\left(\frac{dR_T}{d\theta}\sin^2\delta\right.\right.$$

$$\left.\left.+R_T\sin\delta\cos\delta\frac{d\delta}{d\theta}\right)+2b^4(c+R_T\cos\delta)\left(\frac{dR_T}{d\theta}\cos\delta-R_T\sin\delta\frac{d\delta}{d\theta}\right)\right\}\Big]\cdots\cdots(24)$$

$$\frac{d^2\delta}{d\theta^2}=\frac{-d}{K^2}\Big[-\sin(-\theta-\beta)\left(-1-\frac{d\beta}{d\theta}\right)K-\cos(-\theta-\beta)\times$$

$$\left\{d\frac{dF}{d\theta}\cos(-\theta-\beta)-Fd\sin(-\theta-\beta)\left(-1-\frac{d\beta}{d\theta}\right)+\frac{dE}{d\theta}\sin(\beta+\delta)\right.$$

$$+E\cos(\beta+\delta)\left(\frac{d\beta}{d\theta}+\frac{d\delta}{d\theta}\right)+(F+1)\frac{dR_T}{d\theta}\cos(\beta+\delta)$$

$$\left.+R_T\frac{dF}{d\theta}\cos(\beta+\delta)-R_T(F+1)\sin(\beta+\delta)\left(\frac{d\beta}{d\theta}+\frac{d\delta}{d\theta}\right)\right\}\Big]\cdots\cdots(25)$$

$$\frac{d^2R_T}{d\theta^2}=\frac{dE}{d\theta}\cdot\frac{d\delta}{d\theta}+E\frac{d^2\delta}{d\theta^2},\qquad \frac{d^2\beta}{d\theta^2}=\frac{dF}{d\theta}\cdot\frac{d\delta}{d\theta}+F\frac{d^2\delta}{d\theta^2}\cdots\cdots(26),\ (27)$$

となる。式(23)のGは楕円の曲率半径の計算に必要である。よって式(20)をθで微分して次式が得られる。

$$\frac{d^2\varphi_1}{d\theta^2}=\frac{1}{d\cos\varphi_1}\Big[\frac{d^2R_T}{d\theta^2}\sin(\beta+\delta)+d\sin\varphi_1\left(\frac{d\varphi_1}{d\theta}\right)^2+2\frac{dR_T}{d\theta}\cos(\beta+\delta)\left(\frac{d\beta}{d\theta}+\frac{d\delta}{d\theta}\right)$$

$$-R_T\sin(\beta+\delta)\left(\frac{d\beta}{d\theta}+\frac{d\delta}{d\theta}\right)^2+R_T\cos(\beta+\delta)\left(\frac{d^2\beta}{d\theta^2}+\frac{d^2\delta}{d\theta^2}\right)\Big]\cdots\cdots(28)$$

3．4　従動節の往き行程の始点と終点の角加速度　図１において楕円カムのC点（$\delta=0°$）とE点($\delta=180°$）はそれぞれ従動節の往き行程の始点と終点であるからその位置における $d^2\varphi_1/d\theta^2$ は $\delta=0°$, $180°$で計算した結果次式が得られる。

$$\delta=0°,\quad \frac{d^2\varphi_1}{d\theta^2}=\frac{b^2-a^2+ac}{a\sqrt{d^2-(a-c+f)^2}}\cdots\cdots(29)$$

$$\delta=180°,\quad \frac{d^2\varphi_1}{d\theta^2}=-\frac{a^2-b^2+ac}{a\sqrt{d^2-(a+c+f)^2}}\cdots\cdots(30)$$

§４　カムの曲率半径，押進め角，滑り率

楕円カムの曲率半径を求めるには式(2)の $x_T=-R_T\cos\delta$, $y_T=R_T\sin\delta$ をθで微分して次の曲率半径の式

$$\rho_T=\frac{\left\{\left(\frac{dx_T}{d\theta}\right)^2+\left(\frac{dy_T}{d\theta}\right)^2\right\}^{3/2}}{\frac{d^2x_T}{d\theta^2}\ \frac{dy_T}{d\theta}-\frac{d^2y_T}{d\theta^2}\ \frac{dx_T}{d\theta}}\cdots\cdots(31)$$

に代入すればよい。その結果次式が得られる。

$$\rho_T=\frac{(R_T{}^2+E^2)^{3/2}}{R_T{}^2-R_TG+2E^2}\cdots\cdots(32)$$

ただしR_T, E, Gはそれぞれ式(3), (15), (23)に示される。

押進め角ϕは図１において接触点 T の法線 TP とT点が従動節に属する場合の速度の方向すなわちBTに垂直な方向となす角であるので，平板従動節においては$\phi=\angle KBT$ となる。よって$\overline{BK}=s$ とす

れば，sはB点から接触点までの距離を示すから，sにより従動節上の接触点の位置がわかる。

法線TPのP点はカムと従動節の瞬間中心 I_{12} だから $\omega_1\overline{AP}=\omega_2\overline{BP}$ で $\omega_1=d\theta/dt$，$\omega_2=d\varphi_1/dt$ だから次式が得られる。

$$\frac{\overline{AP}}{\overline{BP}}=\frac{d\varphi_1}{d\theta},\qquad \overline{AP}+\overline{BP}=d \quad\cdots(33)$$

$$\overline{AP}=d\times\frac{\dfrac{d\varphi_1}{d\theta}}{1+\dfrac{d\varphi_1}{d\theta}},\qquad \overline{BP}=\frac{d}{1+\dfrac{d\varphi_1}{d\theta}} \quad\cdots(34)$$

押進め角ϕとsは次式から求められる。

$$\tan\phi=\frac{f}{s},\qquad s=\overline{BP}\cos\varphi_1=\frac{d\cos\varphi_1}{1+\dfrac{d\varphi_1}{d\theta}} \quad\cdots(35),\ (36)$$

次に$\overline{PT}$の長さは図1より

$$\overline{PT}=\overline{BP}\sin\varphi_1-f=\frac{d\sin\varphi_1}{1+d\varphi_1/d\theta}-f \quad\cdots(37)$$

となり，カムと従動節の滑り率をそれぞれσ_1，σ_2とすれば前報[2]より次式で与えられる。

$$\sigma_1=\frac{\overline{PT}}{\rho_T},\qquad \sigma_2=\frac{\overline{PT}}{\rho_T-\overline{PT}} \quad\cdots(38),\ (39)$$

§5 往きと戻り行程のカムの回転角

カムがC，E点で従動節と接触するときのカムの回転角をそれぞれ θ_C，θ_E とし，カムの往き行程の回転角をθ_o，戻り行程のそれをθ_rとすれば図1において

$$\theta_C=-(90^\circ+\varphi_0),\qquad \theta_E=90^\circ-(\Psi+\varphi_0)$$

となるので，θ_o，θ_r は次式のようになる。

$$\theta_o=\theta_E-\theta_C=180^\circ-\Psi,\qquad \theta_r=360^\circ+\theta_C-\theta_E=180^\circ+\Psi \quad\cdots(40),\ (41)$$

よって従動節の揺動角が指定されれば θ_o，θ_r は定まる。これから明らかに往き行程が戻りより短かくなるので，カムの回転方向を逆にして仕事を行う往き行程を長くする方法がよい。

§6 計　算　例

カム機構の各寸法を例えば$a=3$，$b=2$，$c=2$，$d=8$，$f=0$にとった場合の平板従動節のφ，$d\varphi_1/d\theta$，$d^2\varphi_1/d\theta^2$を式(11)，(20)，(28)より計算し，横軸をθとして図2に示す。式(1)，(9)より$\varphi_0=7.18076^\circ$，$\Psi=31.50143^\circ$ となり，$\theta_o=148.49857^\circ$，$\theta_r=211.50143^\circ$ となる。揺動角Ψは指定される必要があるので，その場合については後述する。図2においてこのカムの運動は始点において緩やかにスタートすることと戻り行程の運動が滑らかなことがわかる。

図3は図2のデータでカム曲率半径ρ_Tとsと滑り率σ_1，σ_2を各δに対して求めたもので，カム上のどの位置で最大値をとるかを示した。滑り率 σ_1 は $\delta=180^\circ$ すなわち往き行程の終点を少し過ぎた所で最大となり $\sigma_{1max}\doteqdot3.91(\delta\doteqdot185^\circ)$ となる。σ_{1max} としては3～4迄であればよいのでその点良好である。$\delta=180^\circ$ においては$\sigma_1=3.75$であるが，この終点のσ_1を指定した場合を考えねばならぬ。

図4は従動節の滑り率 σ_2 を従動節の平板上にsを横軸としてとったもので，両端で無限大となり，途中で少し高い所を生ずる。

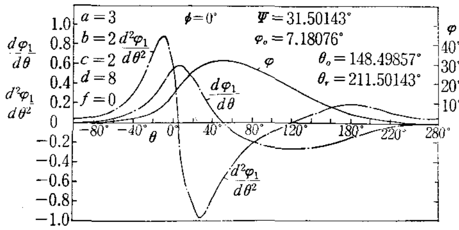


図2　揺動偏心正楕円カムの運動

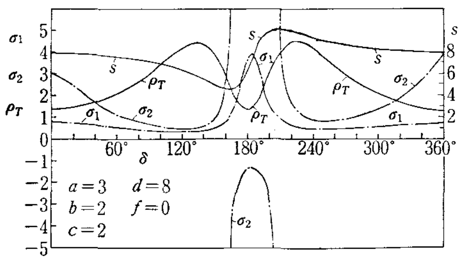


図3　揺動偏心正楕円カムの ρ_T, s, σ_1, σ_2

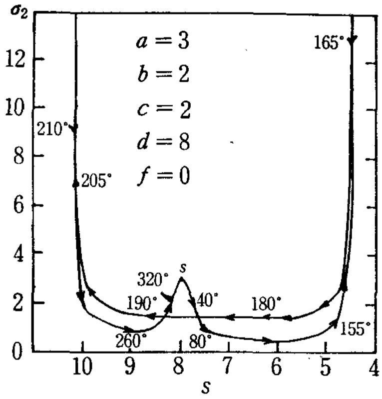


図4　平板従動節上の滑り率 σ_2

§ 7　従動節の揺動角の指定

式(9)において揺動角Ψを指定した場合の a, c, d, f の関係を求める。

$$\Psi=\sin^{-1}\frac{a+c+f}{d}-\sin^{-1}\frac{a-c+f}{d}$$

$$=\sin^{-1}\left\{\frac{a+c+f}{d}\sqrt{1-\left(\frac{a-c+f}{d}\right)^2}-\frac{a-c+f}{d}\sqrt{1-\left(\frac{a+c+f}{d}\right)^2}\right\} \quad\cdots\cdots(42)$$

となるので，これから d を求めれば

$$d^2=\frac{2}{\sin^2\Psi}\left[(a+f)^2+c^2-(a-c+f)(a+c+f)\cos\Psi\right] \quad\cdots\cdots(43)$$

が得られる。このようなカム機構においては d の長さを基準にとった方が便利であるので $d=1$ とする。かたより量fを上式を変形して求めれば

$$f=\sqrt{\frac{d^2\sin^2\Psi/2-c^2(1+\cos\Psi)}{1-\cos\Psi}}-a \quad\cdots\cdots(44)$$

となり，$a+f$ を指定すれば上式から

$$c=\sqrt{\frac{d^2\sin^2\Psi/2-(a+f)^2(1-\cos\Psi)}{1+\cos\Psi}} \quad\cdots\cdots(45)$$

が得られる。図5は $d=1$, $\Psi=10°\sim30°$, $a+f=0.1\sim0.9$ の場合の c の値を式(45)より求めて $a+f$ に対して示す。Ψ が大きい程 c は増し，$a+f$ が大きい程減少する。

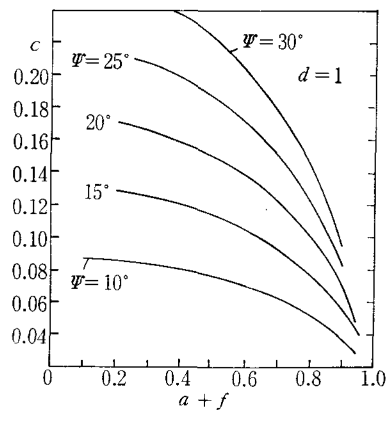


図5　Ψ, d, $a+f$ を指定したときの c

§8　往き行程の始点と終点における従動節の角加速度が等しい場合

往き行程の始点と終点における従動節の角加速度の絶対値を等しくするためには式(29)，(30)の絶対値を等しいとおけば

$$\{(a+c+f)^2-(a-c+f)^2\}b^4+2a\{-2cd^2+(a+c)(a-c+f)^2-(a-c)(a+c+f)^2\}b^2$$
$$+4a^2cd^2+a^2(a-c)^2(a+c+f)^2-a^2(a+c)^2(a-c+f)^2=0$$

となるので，これから b を求めて吟味の結果

$$b^2=a\times\frac{d^2-f^2+a^2-c^2-\sqrt{(d^2-f^2+a^2-c^2)^2+4(a+f)(-ad^2+af^2+a^2f-c^2f)}}{2(a+f)} \quad\cdots\cdots(46)$$

となる。$f=0$ の場合は次式のようになる。

$$f=0,\quad b^2=\frac{1}{2}\{d^2+a^2-c^2-\sqrt{(d^2+a^2-c^2)^2-4a^2d^2}\} \quad\cdots\cdots(47)$$

しかし b には最小限の値がある。図1において C 点の曲率半径は b^2/a だから φ_1 が漸次増加するためにはカムの最小半径はこの曲率半径より小でなければならぬ。すなわち

$$\frac{b^2}{a}>a-c,\qquad b>\sqrt{a(a-c)} \quad\cdots\cdots(48)$$

今 Ψ，d，a，f を指定すれば式(45)から c が求まる。ただし $a>c$ が望ましい。式(46)から b が求まるが，これが式(48)を満足すればよい。a の最小値 $a_{min}=c$ とし，式(45)の c に代入すれば

$$a_{min}=\frac{1}{2}\{\sin\Psi\sqrt{d^2-f^2}-f(1-\cos\Psi)\} \quad\cdots\cdots(49)$$

が得られ，$\Psi=10°\sim60°$，$d=1$，$f=-0.5\sim0.5$ の場合の a_{min} の値を求めて図6に示す。Ψ と f が大きい程 a_{min} は大となる。図によって f が指定された場合の a_{min} がわかる。

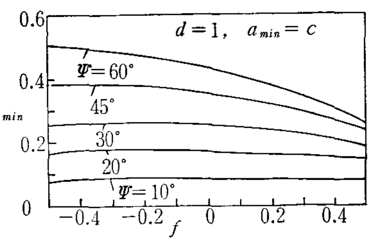


図6　長軸半径の最小値

図7は $\Psi=30°$，$d=1$，$f=-0.2$，0，0.2 の場合の各 a に対する b，c の値を示す。f の変化により c は a が増すにつれ大きく変わるが，b は常に a より僅かに大となる。

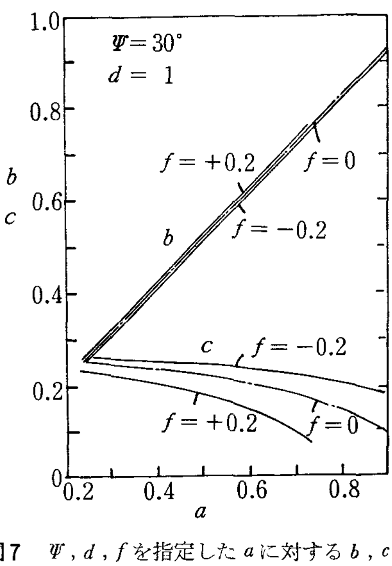


図7　Ψ，d，f を指定した a に対する b，c

次に始点と終点の角加速度が等しい場合のその角加速度を求めるために式(45)，(46)を式(29)，(30)に代入して整理すれば

$$\left|\frac{d^2\varphi_1}{d\theta^2}\right|_{\delta=0°}=\left|\frac{d^2\varphi_1}{d\theta^2}\right|_{\delta=180°}=\tan\frac{\Psi}{2} \quad\cdots\cdots(50)$$

が得られ，a，f の値に無関係に Ψ によって定まる。

例えば $\Psi=30°$，$f=0$，$a=0.3\sim0.9$ の場合，式(45)，(46)より c，b の値を求めたものを表1に示し，それらのデ

ータで $d^2\varphi_1/d\theta^2$ を求めたものを δ に対して図8に示す。図から最大の $d^2\varphi_1/d\theta^2$ は始点の 0.267949 から約0.08だけ増加するが各 a に対して殆んど同じなので a の影響のないことがわかる。

次に $\Psi=30°$, $a=0.3$ を指定し各 f に対する b, c を求めたものを表2に示す。

これらのデータで $d^2\varphi_1/d\theta^2$ を δ に対して求めたものを図9に示す。図から $d^2\varphi_1/d\theta^2$ の最大値は各 f に対してほぼ同一であり，以上から最大角加速度は a, f の値に関係なくほぼ一定であることがわかる。

図10，11は往き行程の始点と終点の等角加速度の場合の $\Psi=30°$, $d=1$, $f=0.1$, $a=0.3$ の表2のデータにおける φ, $d\varphi_1/d\theta$, $d^2\varphi_1/d\theta^2$ と ρ_T, s, σ_1, σ_2 を示す。カムの最大滑り率 $\sigma_{1max}\fallingdotseq1.9$ で $\delta=210°$ となり終点を少し過ぎた所に生ずる。

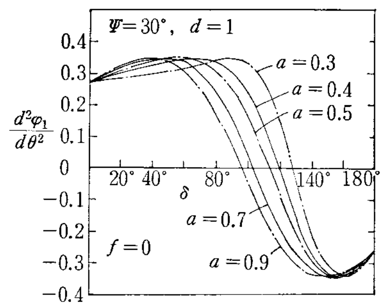


図8 等角加速度の場合の各 a の $d^2\varphi_1/d\theta^2$

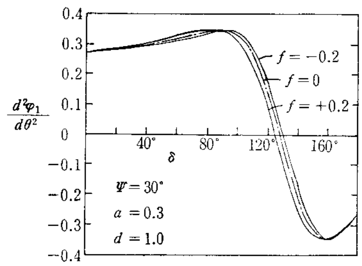


図9 等角加速度の場合の f による $d^2\varphi_1/d\theta^2$

表1 $\Psi=30°$, $f=0$, $d=1$, $\tan 15°=0.267949$

a	b	c	σ_{1E}
0.3	0.3105829	0.2460195	1.698
0.4	0.4141105	0.2355840	1.482
0.5	0.5176381	0.2214455	1.346
0.6	0.6211657	0.2028311	1.248
0.7	0.7246933	0.1783448	1.171
0.9	0.9317486	0.0939783	1.030

表2 $\Psi=30°$, $a=0.3$, $d=1$

f	b	c	σ_{1E}
− 0.2	0.3035686	0.2574283	1.815
− 0.1	0.3070958	0.2532102	1.760
0	0.3105829	0.2460195	1.698
0.1	0.3140312	0.2355840	1.629
0.2	0.3174421	0.2214455	1.552

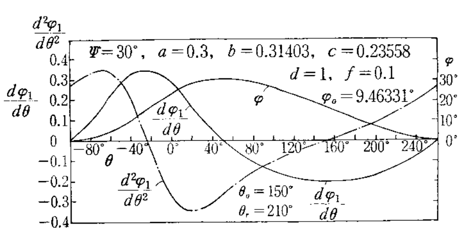


図10 等角加速度で $f=0.1$ の従動節の運動

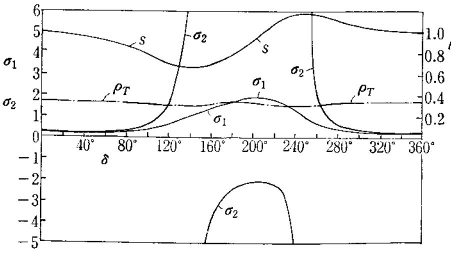


図11 図10のデータによる ρ_T, s, σ_1, σ_2

§9 カムの滑り率

図3，11において往き行程の始点の滑り率 σ_{1C} よりも終点における σ_{1E} が高い値になっている。この点の滑り率が極端に大となればカムの曲率半径が小さくなって摩耗が大となるので，ある値に制限しなければならぬ。

始点においては $d\varphi_1/d\theta=0$, $\sin\varphi_1=\sin\varphi_0=(a-c+f)/d$ から式(37)より $\overline{PT}=a-c$, $\rho_T=b^2/a$ から式(38)，(39)より

$$\delta=0^\circ,\quad \sigma_{1C}=\frac{a(a-c)}{b^2},\quad \sigma_{2C}=\frac{a(a-c)}{b^2-a^2+ac}\quad\cdots\cdots(51),\ (52)$$

終点において $d\varphi_1/d\theta=0$，$\sin(\varphi_0+\Psi)=(a+c+f)/d$ から式(37)より $\overline{PT}=a+c$，$\rho_T=b^2/a$ から

$$\delta=180^\circ,\quad \sigma_{1E}=\frac{a(a+c)}{b^2},\quad \sigma_{2E}=\frac{a(a+c)}{b^2-a^2-ac}\quad\cdots\cdots(53),\ (54)$$

が得られるので，式(51)，(53)より次のことが成立つ。

$$\sigma_{1E}>\sigma_{1C}\quad\cdots\cdots(55)$$

図１の D，F 点のカムの滑り率 σ_{1D}，σ_{1F} を求めるために図12において D 点での接触の場合 $\overline{TP}=\overline{DP}$ となり，$\overline{DP}$ と D 点の曲率半径 ρ_D は図12(a)と式(38)より次式のようになる。

$$\overline{TP}=\overline{DP}=d\sin\varphi_{1D}-c\tan\varphi_{1D}-f$$

$$=b-\frac{c(b+f)}{\sqrt{d^2-(b+f)^2}}\quad\cdots\cdots(56)$$

$$\rho_D=a^2/b\quad\cdots\cdots(57)$$

$$\sigma_{1D}=\frac{b}{a^2}\left\{b-\frac{c(b+f)}{\sqrt{d^2-(b+f)^2}}\right\}\quad\cdots\cdots(58)$$

F 点の接触では図12(b)より次式が得られる。

$$\overline{TP}=\overline{FP}=b+\frac{c(b+f)}{\sqrt{d^2-(b+f)^2}},\qquad \rho_F=\frac{a^2}{b}\quad\cdots\cdots(59),\ (60)$$

$$\sigma_{1F}=\frac{b}{a^2}\left\{b+\frac{c(b+f)}{\sqrt{d^2-(b+f)^2}}\right\}\quad\cdots\cdots(61)$$

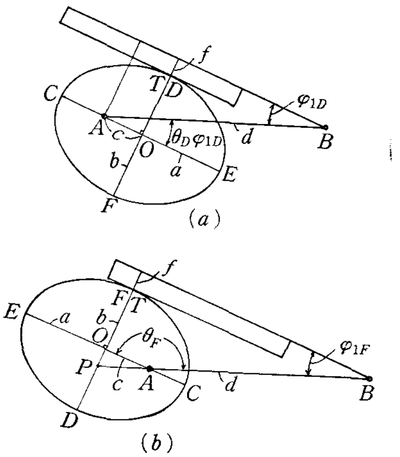


図12　D，F 点での接触

よって式(58)と式(61)を比較すれば

$$\sigma_{1F}>\sigma_{1D}\quad\cdots\cdots(62)$$

となるが，σ_{1E} と σ_{1F} の大小は a，b，d の長さによって変わる。表１，２にそれらのデータの場合の σ_{1E} を示す。

§10　往き行程の始点の角加速度を零にする場合

始点の角加速度が零の場合は式(29)より

$$b=\sqrt{a(a-c)}\quad\cdots\cdots(63)$$

が得られ，常に $b<a$ だから E 点の σ_{1E} が最大となる。よって式(53)に式(63)を代入すれば

$$c=\frac{\sigma_{1E}-1}{\sigma_{1E}+1}a\ ,\qquad b=\sqrt{\frac{a(a+c)}{\sigma_{1E}}}\quad\cdots\cdots(64),\ (65)$$

となるので，これを式(45)に代入すれば次の a の２次式が得られる。

$$a^2\{2(\sigma_{1E}^2+1)-4\sigma_{1E}\cos\Psi\}+2af(\sigma_{1E}+1)^2(1-\cos\Psi)$$

$$+(\sigma_{1E}+1)^2\left\{f^2(1-\cos\Psi)-\frac{d^2\sin^2\Psi}{2}\right\}=0\quad\cdots\cdots(66)$$

これから吟味の結果 a を求めれば次のようになる。

$$a=\frac{-f(\sigma_{1E}+1)^2(1-\cos\Psi)+\sin\Psi(\sigma_{1E}+1)\sqrt{(d^2-f^2)(\sigma_{1E}-1)^2+2\sigma_{1E}d^2(1-\cos\Psi)}}{2(\sigma_{1E}-1)^2+4\sigma_{1E}(1-\cos\Psi)} \quad \cdots\cdots(67)$$

この式により，Ψ，d，σ_{1E}，f が指定されれば a が求められ，式(64)から c，式(65)から b が求められる。これらの結果を式(30)に代入すれば終点の $d^2\varphi_1/d\theta^2$ が得られるのでこれを表1と図13に示す。

図13から f を増せば a は減ずるが $d^2\varphi_1/d\theta^2$ は増すことがわかるので f は0の前後に取る必要がある。

表3 $\Psi=30°$，$d=1$，$\sigma_{1E}=2$

f	−0.2	−0.1	0
a	0.6757472	0.6424533	0.6051737
b	0.5517453	0.5245609	0.4941222
c	0.2252491	0.2141511	0.2017246
$d^2\varphi_1/d\theta^2$	−0.6316886	−0.6550237	−0.6830127

f	0.1	0.2	−0.2($\sigma_{1E}=3$)
a	0.5639474	0.5187354	0.4932126
b	0.4604611	0.4235456	0.3487540
c	0.1879825	0.1729118	0.2466063
$d^2\varphi_1/d\theta^2$	−0.7179617	−0.7638610	−0.5859155

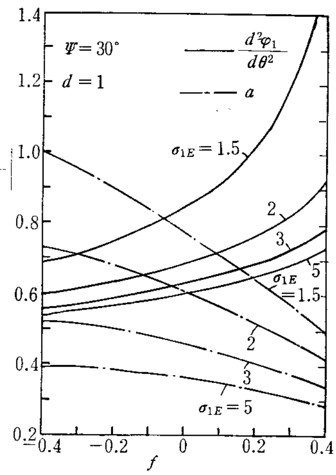


図13 始点の角加速度が零の場合

図14は $\Psi=30°$，$d=1$，$\sigma_{1E}=2$ の場合の $f=-0.1$ と 0.1 を指定した場合と $\sigma_{1E}=3$ の場合 $f=-0.2$ を指定した時の $d^2\varphi_1/d\theta^2$ と σ_1 の値の変化を各 θ に対して示したものである。f を＋側にとれば a は小さくなるが最大の $d^2\varphi_1/d\theta^2$ が増す。σ_{1E} を増せば a および $d^2\varphi_1/d\theta^2$ が小さくなる。

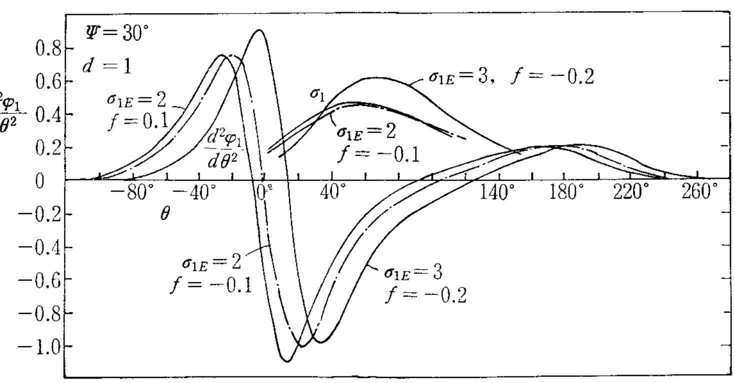


図14 Ψ，d，σ_{1E}，f を指定した $d^2\varphi_1/d\theta^2$ と σ_1

§11 終点の角加速度を零にする場合

往き行程の終点において従動節の慣性力により従動節がカムから離れるのを避けるために終点の角加速度を零にすれば式(30)から

$$b=\sqrt{a(a+c)} \quad \cdots\cdots(68)$$

が得られ，$c>0$ から $b>a$ となる。この場合のカムの E，F 点の滑り率を求めるために式(53)，(61)に式(68)を代入すれば

$$\sigma_{1E}=1, \qquad \sigma_{1F}=1+\frac{c}{a}+\frac{bc(b+f)}{a^2\sqrt{d^2-(b+f)^2}} \quad \cdots\cdots(69)$$

となるので，b，c，$b+f$ が正だから

$$\sigma_{1F} > \sigma_{1E} \quad ただし \quad b>a \qquad \cdots\cdots(70)$$

が得られる。そこで σ_{1F} を指定し a，c が求めたいのであるが困難なので Ψ，d，a，f を指定し，式(45)より c，式(68)より b，式(51)，(61)，(30)より σ_{1C}，σ_{1F}，$\delta=0$ の $d^2\varphi_1/d\theta^2$ を求めたものを図15に示す。図から a が大きい程 σ_{1F}，$d^2\varphi_1/d\theta^2$ は小さくなるが σ_{1C} は大となる。f について言えば f を負にとると σ_{1C}，σ_{1F} は小となるが $d^2\varphi_1/d\theta^2$ は逆に大となる。

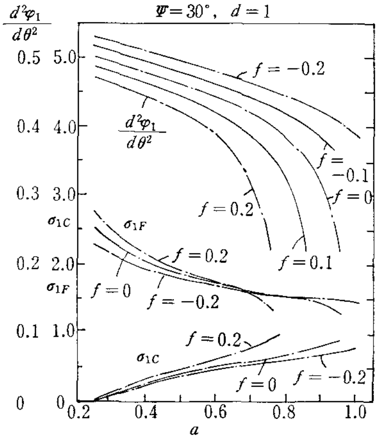


図15　終点の角加速度が零の場合

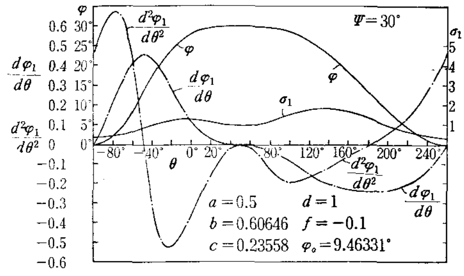


図16　終点の角加速度が零の $\Psi=30°$ の場合の運動と σ_1

例えば $\Psi=30°$，$d=1$，$a=0.5$，$f=-0.1$ とすれば $b=0.6064586$，$c=0.2355840$，$\sigma_{C1}=0.359$，$\sigma_{1F}=1.807$，$d^2\varphi_1/d\theta^2=0.478$ となるので，これらのデータで φ，$d\varphi_1/d\theta$，$d^2\varphi_1/d\theta$，σ_1 を図16に示す。

σ_{1C} を指定すれば式(51)，(68)より

$$c=\frac{1-\sigma_{1C}}{1+\sigma_{1C}}a \qquad \cdots\cdots(71)$$

が得られ $c>0$ なるために $\sigma_{1C}<1$ でなければならぬ。式(71)を式(45)の左辺に代入して a を求めれば吟味の結果次式が得られる。

$$a=\frac{-f(1+\sigma_{1C})^2(1-\cos\Psi)+(1+\sigma_{1C})\sin\Psi\sqrt{(d^2-f^2)(1-\sigma_{1C})^2-2\sigma_{1C}(1-\cos\Psi)}}{2(1-\sigma_{1C})^2+4\sigma_{1C}(1-\cos\Psi)} \qquad \cdots\cdots(72)$$

$$b=\sqrt{\frac{a(a-c)}{\sigma_{1C}}} \qquad \cdots\cdots(73)$$

よって例えば $\Psi=30°$，$d=1$，$f=-0.4\sim0.4$，$\sigma_{1C}=0.4\sim0.7$ の場合の a，b，c と $\delta=0$ の $d^2\varphi_1/d\theta^2$ を表4と図17に示す。これから f が大きくする程 a，b，c，$d^2\varphi_1/d\theta^2$ が小さくなることがわかる。

表4　$\Psi=30°$，$d=1$，$\sigma_{1C}=0.4$

f	−0.2	−0.1	0	+0.1	+0.2
a	0.56032	0.53819	0.51207	0.48199	0.44791
b	0.66971	0.64326	0.61204	0.57608	0.53535
c	0.24014	0.23065	0.21946	0.20657	0.19196
$d^2\varphi_1/d\theta^2$	0.48378	0.47158	0.45900	0.44573	0.43137

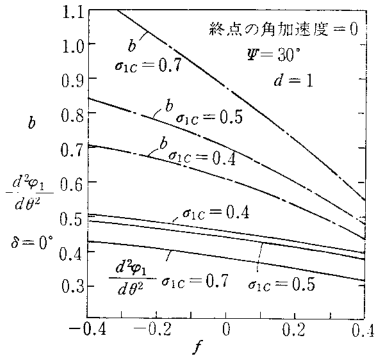


図17 終点の角加速度が零の場合の各 σ_{1C}, f に対する b と $d^2\varphi_1/d\theta^2$

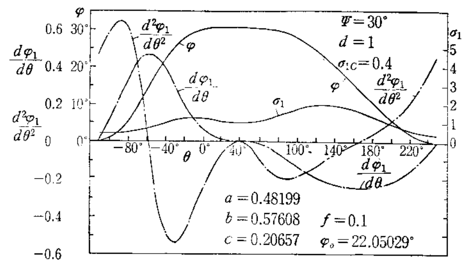


図18 終点の角加速度が零で $\Psi=30°$, $f=0.1$ の運動と σ_1

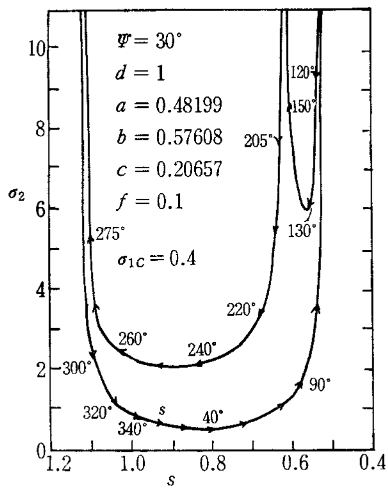


図19 図18の場合の平板上の σ_2

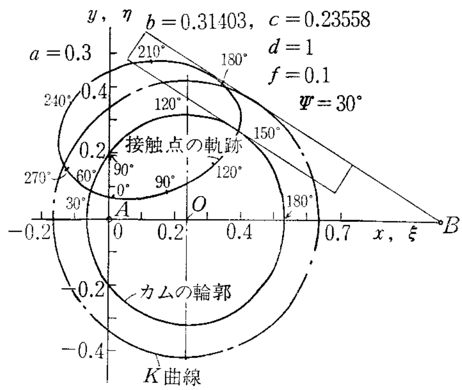


図20 図10の等角加速度の場合のカムの輪郭と接触点の軌跡

図18は $\Psi=30°$, $d=1$, $\sigma_{1C}=0.4$, $f=0.1$ の場合の従動節の運動と σ_1 を示す。$\sigma_{1max}\fallingdotseq 2\,(\delta\fallingdotseq 245°)$ であることがわかる。図19は図18の場合の従動節上の点を示す s に対する σ_2 を示したもので行程の途中で無限大となる。

§12 カムの輪郭と接触点の軌跡

カムは a, b を半径とする楕円で輪郭は式(2), (4), (3)で示される。図1において接触点 T の法線上の K 点の軌跡はカムより f だけ離れた曲線で式(5)の β を用いて次式で示される。

$$x_K=x_T-f\sin\beta,\quad y_K=y_T+f\cos\beta \qquad (74)$$

次に接触点 T の軌跡は図1より

$$\xi_T=x_T\cos\theta-y_T\sin\theta,\quad \eta_T=x_T\sin\theta+y_T\cos\theta \qquad (75)$$

で求められ，θ は式(6)より定められる。

図20は始点と終点の等角加速度の場合，図21は始点の角加速度が零の場合，図22は終点の角加速度が零の場合のカムの輪郭，K 点の軌跡，接触点の軌跡を示す。いずれも良好な形となる。

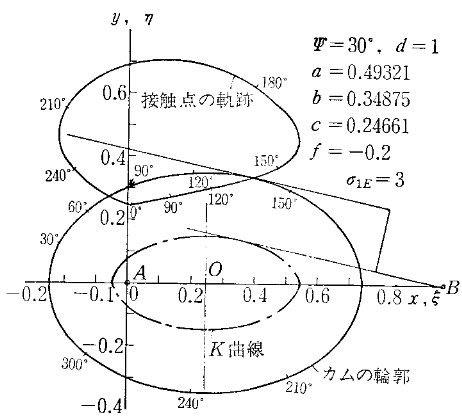


図21　図14の始点の角加速度が零の場合のカムの輪郭と接触点の軌跡

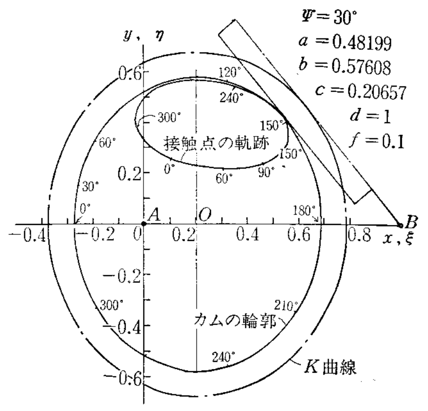


図22　図18の終点の角加速度が零の場合のカムの輪郭と接触点の軌跡

§13　結　　論

平板従動節をもつ偏心正楕円カムにおいて従動節の運動，滑り率等の解析をすることができ，次の結論が得られた。

(1)　従動節の揺動角により往きと戻り行程のカムの回転角が指定され，早戻りさせるためにはカムを内側に回転させなければならない。(2)　揺動角Ψとd，a，fを指定すればcが決定される。(3)　楕円の短半径　bはa，cにより最小値が求まり，往き行程の始点と終点の角加速度を指定すれば決定される。(4)　始点と終点の等角加速度の場合　$d^2\varphi_1/d\theta^2=\tan\Psi/2$となり，$b>a$となる。(5)　カムの滑り率$\sigma_1$について言えばカムの曲率半径が最小の所で近似的に$\sigma_1$が最大となる。$a>b$のときは$\sigma_{1E}>\sigma_{1C}$，$a<b$のときは　$\sigma_{1F}>\sigma_{1D}$　となりそれらの内最大のものを指定してカム装置の各寸法が決定できる。(6)　従動節の滑り率σ_2は従動節の接触面の両端で無限大となるが，始点あるいは終点の角加速度が零の場合は途中で無限大の点を生ずる。

以上の研究において本校学生，野瀬隆文，西森憲章両君の協力を得た。

文　　献

1)　糸島寛典，河野正來：揺動偏心正楕円カムの研究（第１報）—円弧従動節—，呉高専研究報告，12—2，1977
2)　糸島寛典：揺動正楕円カムの研究（第２報）—平板従動節—，呉高専研究報告，12—1，1976

（昭和52年５月31日受付）

円環の振動に関する研究
（第1報　自由，支持振動）

（機械工学科）　野　原　　稔

On the Vibration of the Circular Ring
(1st Report, Free and Supported Vibration)

Minoru NOHARA

The vibration of the circular ring has been dealt as the essential problem of the elastic vibrations. However, both the function and the strength of the ring have an importance as the mechanical elements, but the practical experiment to determine the natural frepuencies of the circular ring has scarecely been investigated.

The vibration of the circular ring with the ball bearing and that of the rotating parts of the various machines have become a serious problem in practice as the necessity of the silent machine increases.

In this paper, the sixteen circular rings were used for the test pieces, and the investigation was carried out by varrying the thickness and the width of the ring in search for the effect of the thickness and the width of the ring on the natural frequencies of the in-plane vibration of the circular ring (supported at the two and three points, and unsupported) and on those of the out-of-plane vibration of the circular ring caused by the deflection in the direction of the axis and by the rotation of the ring.

§1　緒　　言

円環の振動は基本的な弾性振動の問題として取扱われてきたが，機械的要素としてはむしろ機能と強度の面が重視され，その振動数を求める実用的な研究はほとんどなされていない。しかし，静かな機械を作る必要性が増すにつれ，玉軸受や各種回転機械に使用されている円環の振動が問題となってきている。そこで，16個の円環試料を製作し，円環が各種の状態（自由，２方向支持，３方向支持）におかれた場合の面内振動，および軸方向変位とねじりを伴う場合の面外振動について，円環の厚さおよび幅を変化させ，円環厚さ，幅が固有振動数に与える影響を調べ検討した。

§2　記　　号

f：固有振動数	R：円環の平均半径
L：円環幅	H：円環厚さ
P：荷重	E：縦の弾性係数
I：断面二次モーメント	g：重力の加速度
γ：比重量	A：断面積

n：モード数　　　　ρ_0：密　　度
ν：ポアソン比

§3　古典式と近似公式

円環の面内自由振動に対する古典式は

$$f=\frac{1}{2\pi}\sqrt{\frac{E\cdot g}{\gamma}\cdot\frac{I}{AR^4}\cdot\frac{n^2(1-n^2)^2}{1+n^2}}\quad\cdots\cdots(1)$$

と表わされ，円環幅については考慮されていない。また，面外自由振動に対しては，円弧形棒理論と円筒殻の無伸張振動理論とを使用して求められた近似公式がある。

$$f=\frac{\frac{\sqrt{3}}{6\pi}n(n^2-1)\rho}{(1-\nu^2)\left(\frac{\rho}{\kappa}\right)^2\frac{n^2(n^2+1)\rho^2+3}{n^2\rho^2+6(1-\nu)}+n^2+\lambda}\cdot\frac{1}{R}\cdot\sqrt{\frac{E}{\rho_0}}\quad\cdots\cdots(2)$$

ここで，$\kappa=\frac{H}{2R}$，　$\rho=\frac{L}{2R}$，　$\lambda=\frac{1+\nu}{2-1.26\gamma(1-\gamma^4/12)}$ である。

§4　実　　験

4.1　実験用円環

試料とする円環は圧力配管用炭素鋼鋼管（STPG 38）を使用し，円環の厚さ，および幅が円環の固有振動数に与える影響について調べるため，図1に示すような円環を製作した。なお円環の厚さ $H=4$，6，8，10㎜，円環幅 $L=20$，40，60，80㎜，円環の平均半径 $R=102$㎜である。

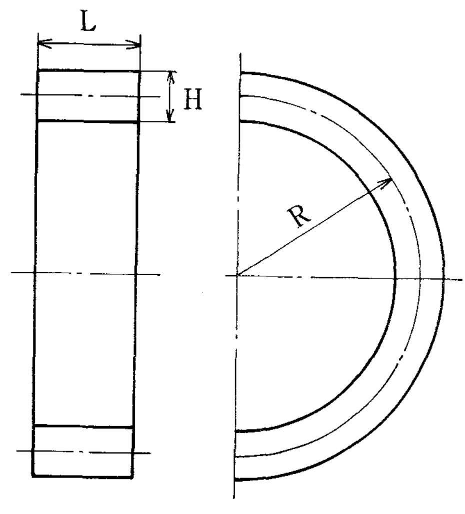


図1　円環試料

4.2　実験方法

4.2.1　面内自由振動

円環の1点を細い銅線でつるし，円環面に垂直な打撃力を半径方向に加えた時，発生する振動を面内自由振動数とする。自由振動における一次($n=2$)，二次($n=3$)のモードは，図2に示すようになると考えられるから，歪ゲージの位置が振動の腹に，つり下げ点が振動の節になるよう打撃点を選べばよいことになる。次に，歪ゲージをホーイストンブリッジにつなぎ，ひずみ増幅用アダプターでバランスをとり，さらに微小電流を増幅器で拡大し，これをシンクロスコープの水平軸に入力する。一方，周波数発振器を使用し，既知周波数をこれに垂直に入れ，リサージュ図形法によって固有振動数を決定した。この時のブロック線図を図3に示す。

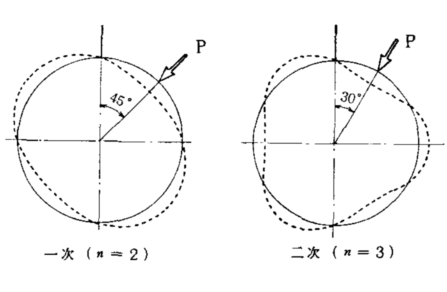


図2　面内自由振動時における振動モード

4.2.2 半径方向（2方向，3方向）を支持した場合の振動

図4に示すような支持装置を使用し円環を支持するが，2方向支持，3方向支持した場合は図5に示すような二次のモードが考えられる。ここで円環を支持した場合，円環と支持点が線接触となるようにボルトの先端に三角柱の支持片を取り付けるが，円環を強く支持しすぎ，荷重が円環に作用しないようにするとともに，打撃することによって円環が傾き，支持点の状態が変化しないよう注意して，図に示すA点を打撃しリサージュ図形法によって固有振動数を決定した。

4.2.3 面外自由振動

軸方向の曲げとねじりを伴う曲げ振動を面外振動とすれば，円環を先のとがったボルトで両側からはさむように支持し，円環の端面に垂直な打撃力を軸方向に加えた時，発生する歪を測定すればよいことになる。面外振動における一次，二次のモードは図6に示すようになると考えられるので，歪ゲージの位置が振動の腹になるように円環を支持装置に取り付け，図6におけるA点を打撃しリサージュ図形法によって固有振動を決定した。この時の歪ゲージのはりつけ状態を図3の点線部に示す。

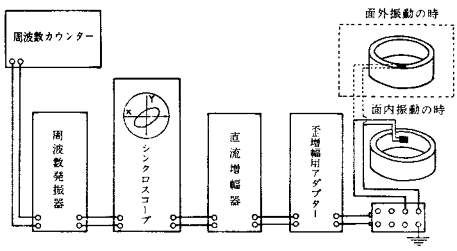


図3　振動数測定用ブロック線図

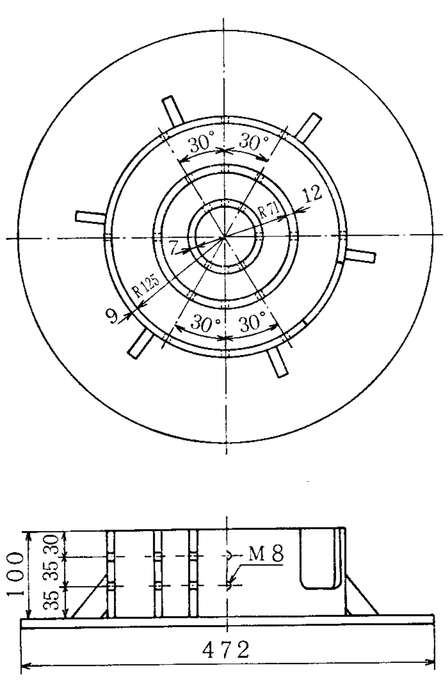


図4　円環支持装置

§5 実験結果

5.1 面内自由振動

円環幅の増加に対する固有振動数の変化を図7，8に示す。いま図7に示す一次のモードの場合，振動数も小さく円環幅の増加による振動数の変化は数ヘルツであり，円環幅の増加に対する変化はあまりみられない。次に図8に示すような二次のモードの場合，円環の増加によって振動数が20〜30 HZ 増大していることがわかる。ここで古典式(1)による値と実験結果を比較すると，円環厚さの薄い場合は比較的よく一致する

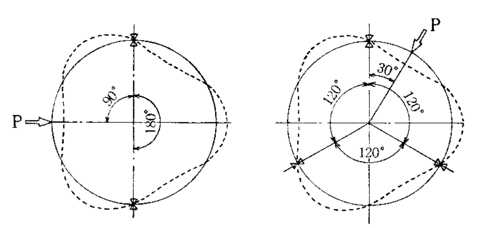


図5　2方向，3方向支持時における振動モード

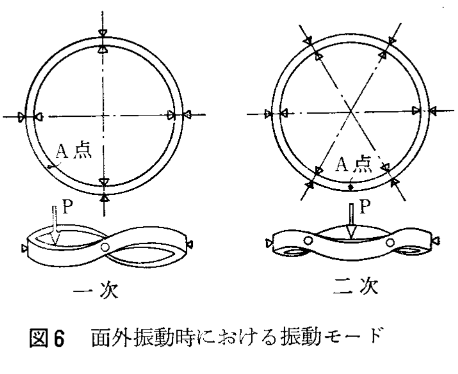


図6　面外振動時における振動モード

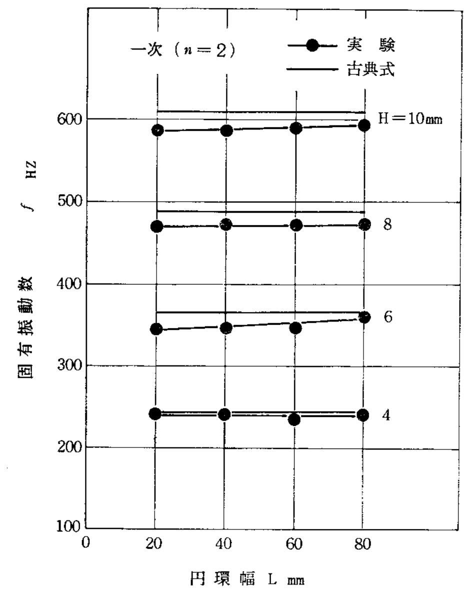


図7 面内自由振動数（一次）

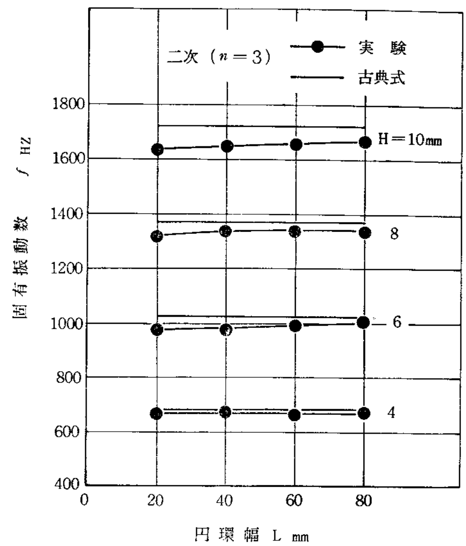


図8 面内自由振動数（二次）

が，円環厚さが増すに従って式（1）が実験結果より大きくなっている。このことは，式（1）が円環断面における回転慣性，剪断変形による影響を考慮していないためと思われる。

5．2 半径方向（2方向，3方向）を支持した場合の振動

2方向，3方向支持における実験結果を図9，10に示す。同じ振動モードが起こる場合において，支持点が多くなれば振動数が高くなる。いま，自由振動における二次の振動を近似的に1点支持とみなし，

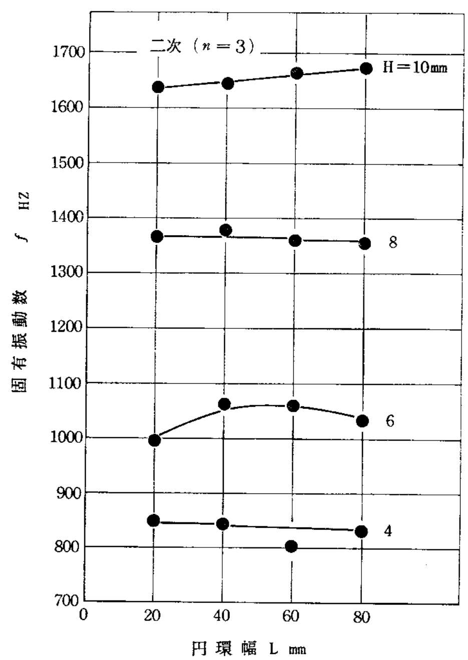


図9 2方向支持時における面内振動数

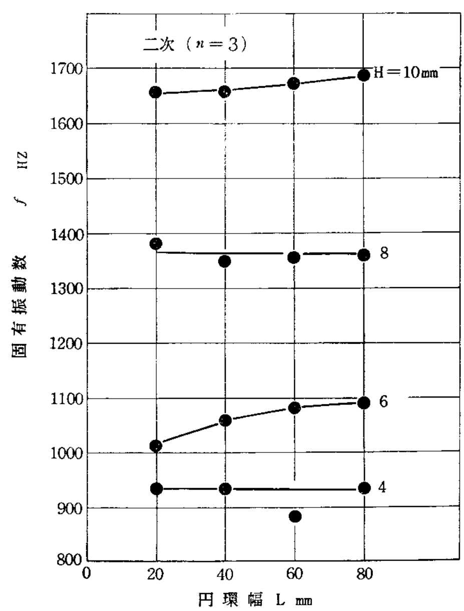


図10 3方向支持時における面内振動数

２方向，３方向支持した場合の二次の振動と比較すれば，円環厚さの薄い $H=4$mm において振動数の変化が顕著で，１点支持と２点支持で約200Hz，２点支持と３点支持で約100Hzの差を生じている。また円環厚さが $H=10$mm と厚くなるといずれの支持の場合も約10Hz程度の差しか生じず，支持点の影響をあまり受けなくなることがわかる。ここで，円環を支持した場合の円環幅に対する影響について考える場合，円環の両側からボルトによる支持であるため支持点において全く荷重が作用していない状態が得にくく，ある程度荷重が作用している状態で実験していることになり，円環幅が振動数に与える影響を考える場合，自由振動の場合で考える方がよいと言える。また，図９，10において，$H4$-$L60$の振動数が小さくなっているが，これは円環の製作誤差によるものと思われ，円環厚さが公称の厚さより200μ程度小さな円環であるためと考えられる。

5．3　面外自由振動

図11に一次の面外振動を示す。図においてわかるように，円環幅が大きくなるに従って振動数が小さく，円環厚さが大きくなるにつれて，振動数の最高値が円環幅の大きい方にずれて行くことがわかる。また図11において，振動数の最高値は円環厚さに関係なく，断面形状比 $L/H \fallingdotseq 5$ の付近で生じている。図12に示すような断面において，円環が $L/H \fallingdotseq 5$ の形状比を持つ時，y 軸まわりの振動は面内振動に相当し，振動数の急激な増加は生じないので，x 軸まわりの曲げ振動，z 軸まわりのねじり振動の成分が大きくなると考えられる。ここで式(2)を使用して得た結果を合せて記すが，式(2)の計算値は実験結果より少し大きめの値を示すと

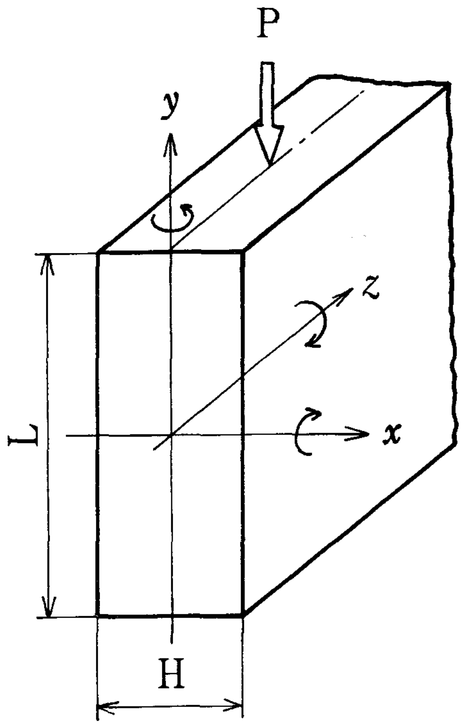


図12　面外自由振動時における円環の状態

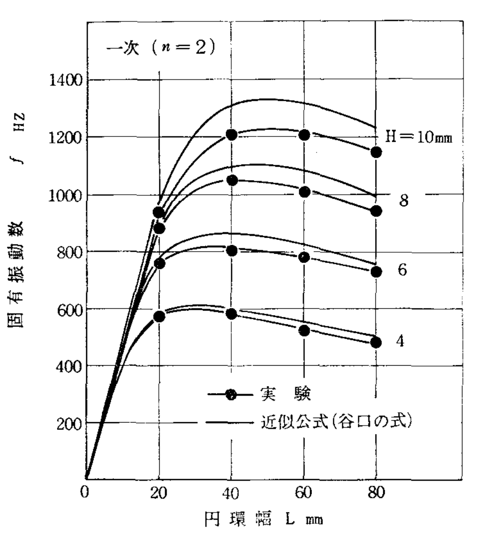


図11　面外自由振動数（一次）

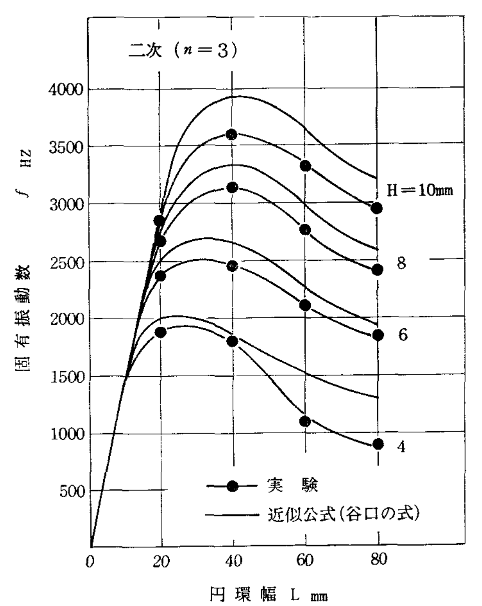


図13　面外自由振動数（二次）

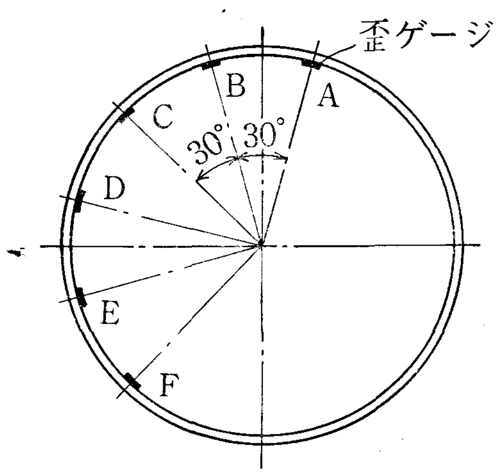
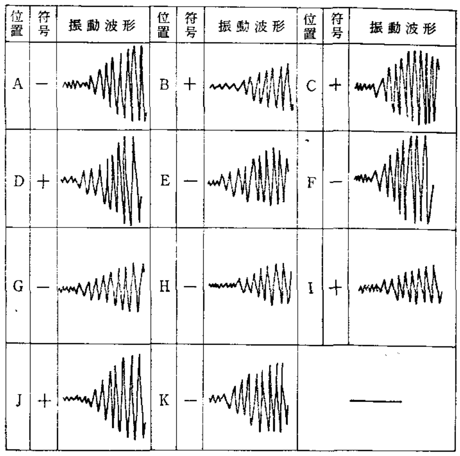


図14 ゲージのはりつけ状態

表1 面内自由振動波形 一次（$n=2$）



位置	符号	振動波形	位置	符号	振動波形	位置	符号	振動波形
A	−		B	+		C	+	
D	+		E	−		F	−	
G	−		H	−		I	+	
J	+		K	−				—

言える。次に，二次の面外振動数を図13に示すが，円環幅の大きくなるに従って，振動数の減少勾配が一次の振動数と比較して大きくなることがわかる。

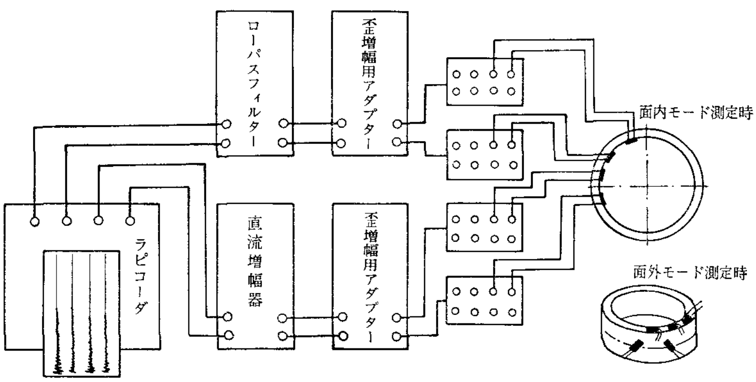


図15 モード測定用ブロック線図

§6 振動モードの測定

円環を打撃した場合，発生するであろうと予想される一次，二次のモードを予想して描いたわけであるが，実際にそのようになっているかどうかを確認する必要がある。いま $H6-L40$ の円環を選び，円環の対称性を考慮して図14に示すように6枚の歪ゲージを 30° 間隔にはり，円環に打撃を加えた場合の A 点に

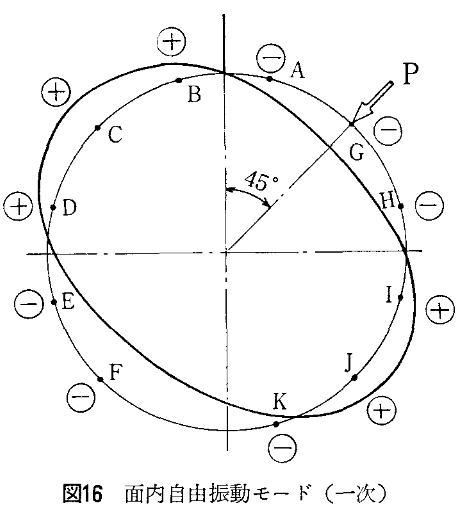


図16 面内自由振動モード（一次）

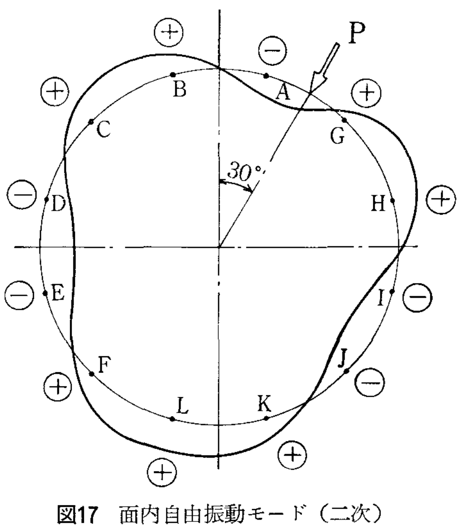


図17 面内自由振動モード（二次）

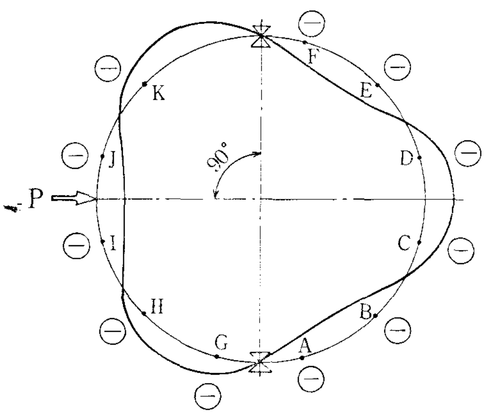


図18　2方向支持時の振動モード

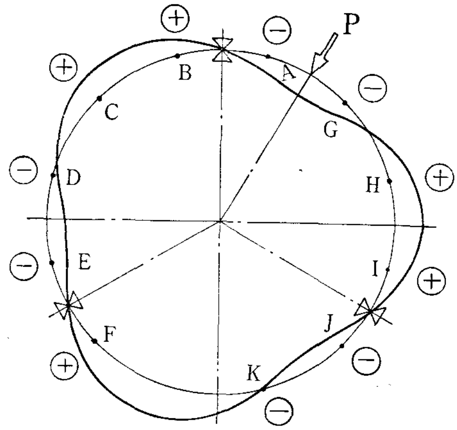


図19　3方向支持時の振動モード

おける歪を基準にとり，B～F点の歪と比較することによって振動モードを求めた。この時のモード測定用ブロック線図を図15に示す。また表1に面内自由振動（一次）の場合の振動波形を表わし，表より描いた振動モードを図16に示す。同様にして求めた振動波形より，面内自由振動（二次）のモードを図17，2方向支持の場合のモードを図18，3方向支持の場合のモードを図19に示す。

§7　結　　論

以上，円環に対する振動数を調べ次のような結論を得た。

1）面内自由振動における一次の場合，振動数は円環幅にほとんど関係しないが，二次の場合，振数動は円環幅に関係し，円環幅 $L=20$㎜ と $L=80$㎜ では約20HZの差を生じる。

2）振動次数が同じ場合，円環厚さの薄い環では支持点の数によって，振動数にかなりの差を生じるが，円環が厚くなると支持点の数によって振動数の差はほとんどなくなる。

3）面外振動における一次の場合，円環厚さに関係なく，$L/H \fallingdotseq 5$付近で振動数が最大となる。おわりに本研究にあたり，御指導いただいた広島大学工学部日高照晃氏に感謝の意を表します。

参　考　文　献

1）S.S. Rao and V. Sundararajan : Trans. ASME, Ser. E, Vol. 36, No. 3 (1969—9), p. 620.
2）遠藤・谷口：機械学会論文集，34—268（昭43-12），2119.
3）遠藤・谷口：機械学会論文集，36—288（昭45-8），1297.
4）C.M. Harris and C.E. Crede : Shock and Vibration Handbook (McGraw-Hill, New York, 1961).
5）S. Timoshenko,（昭44），390，東京図書.
6）T. Potma,（昭49），13，共立出版.

（昭和52年5月20日受付）

吸気の脈動に関する研究

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A Study of Pulsation of Suction Air

Yuji KAWAGUCHI and Isao KUBOTA

Measuring of the suction air quantity, which influences the internal combustion engine performance, is very important, though it is not necessarily easy because of the unsteady flow. As on the differential pressure type flowmeter the pressure difference before and behind the measuring nozzle is proportional to square of the flow rate, the correlation between the mean values of pressure difference and of flow rate varies according to the amplitude of periodic pulsation of the air flow through a nozzle. Therefore, if we apply the ordinary formula in this case, the flow rate is always calculated excessive ; the larger the amplitude, the larger the error. In order to measure the flow rate accurately, it is necessary to change the periodic flow into the approximately steady one.

In this paper we report on the characteristics of suction air flow of a single cylinder type Diesel engine and on the alteration of the pulsatory flow into the steady one.

§1　緒　　言

内燃機関の吸入空気量はエンジンの性能を左右するもので，その測定は非常に重要な意味を持つが，正確にこれを測定することは決して簡単ではない。なぜならばこの場合の空気流は，定常流ではなく脈動流であるからである。すなわち普通の差圧流量計を用いて測定しても，ノズル前後の圧力差はガス流量のほぼ二乗に比例するので，ノズル前後の圧力差の平均値と平均流量との関係は脈動の振幅によって変化し，定常流のときの計算式を用いて流量を算出すると，常に流量が過大に計算されることになり，脈動振幅が大きい程この誤差は大きくなる。したがって正確に吸気流量を測定するためには，脈動を消して定常流に近い気流に変換しなければならない。

本研究は，先ず単シリンダのディーゼル機関の吸気脈動の特性を調べ，その脈動特性におよぼすサージタンクの効果を実験的に検討したものである。

以下その内容を報告する。

§2　実 験 装 置

実験装置の概要を図1に示す。

機関①を吸気管⑫を介して 600 *l* のサージタンク②に接続し，更に連絡パイプ⑬を介して 128 *l* のサージタンク④とつなぎ，④入口には導管⑤を接続し，⑤の先端にノズル⑥を取付ける。③は絞り弁である。ノズル背後の圧力はビニールホース⑦を介して圧力センサー⑧で電圧に変換され，アンプで増幅されブラウン管オッシロに波形となって表わされる。⑨は水柱マノメータでビニールホース⑩を取付け，

⑧を取外して⑦と⑩をつなげばノズル背後の平均圧力が測定され，普通の差圧流量計としての測定値が得られる。更に⑩を開口⑪に接続すれば 128 l サージタンク内の圧力が，また開口⑭につなげば 600 l のタンク内の圧力が測定できることになる。必要に応じ②と④を外して⑫と⑤を接続すれば，サージタンクなしの直接流を測定することもできる。写真1は本実験装置の全景である。

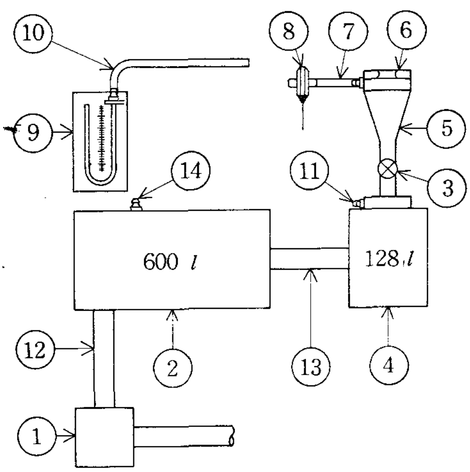


図1　実　験　装　置

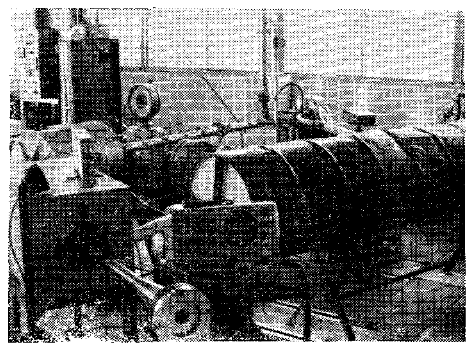


写真1　実　験　装　置　全　景

§3　実 験 の 内 容

実験機関の要目を表1に示す。

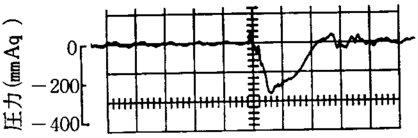
表1　　ディーゼル機関主要目表

項　　目	内　　容
型　　式	立型4サイクル，水冷式
シ リ ン ダ 数	1
燃 焼 室 型 式	予 燃 焼 室 式
出　力（PS/r.p.m.）	10/900～11/1000
圧　縮　比	17.3
内 径 × 行 程（mm）	φ120 × 170
平均有効圧力（kg/cm²）	5.15 ～ 5.20

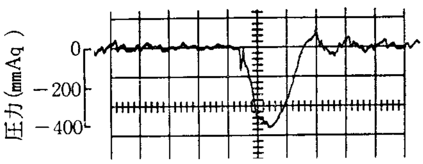
3．1　脈動波形の特性

先ず吸入空気の脈動状況を知るために，前記実験装置を用いて，ブラウン管に波形をえがかせ，それを写真撮影した。

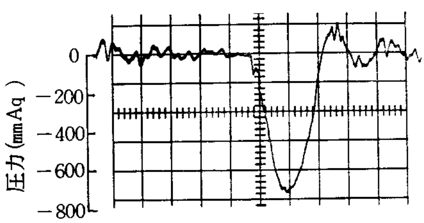
運転条件はアイドリングで500r.p.m.，700r.p.m.，および 1,000r.p.m. とし，ノズルは φ36mm を使用した。また，サージタンクを全然使用しない場合，128 l のサージタンクをとりつけた場合，および 600 l のサージタンクを併用した場合につき，脈動波形がどう変化するかを調べた。128 l のサージタンクはメーカ推薦の購入品で，600 l サージタンクは200 l のドラム缶3個を溶接してつなぎ合わせた自製のものである。なお，ノズル直後の圧力を圧力センサーに導くビニールホース⑦の長さが，ブラウン管上の波形に影響することが考えられるので，ホース長 l=1cm，3cm，10cm，2m，10m の5種類を用いて，その影響を見ることにした。その結果を写真2～14に示す。縦軸は圧力，横軸はクランク角度である。



a) 500 r.p.m.

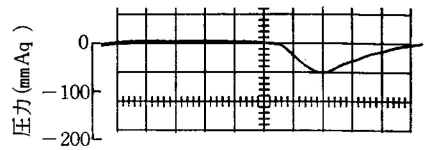


b) 700 r.p.m.

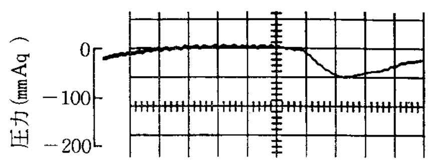


c) 1000 r.p.m.

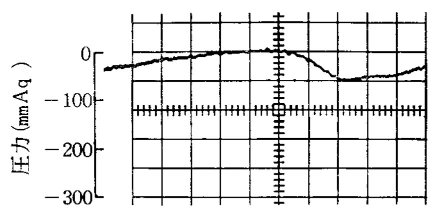
写真 2 (a〜c)　直接，l=10cmの場合



a) 500 r.p.m.

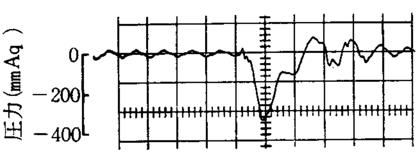


b) 700 r.p.m.

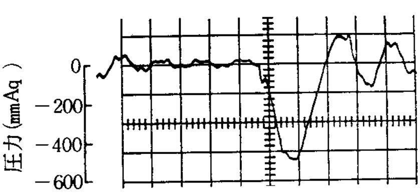


c) 1000 r.p.m.

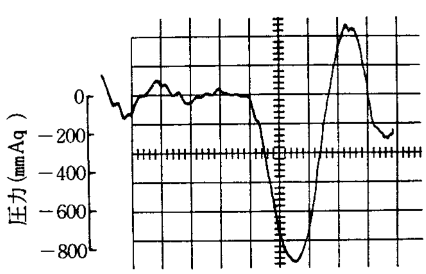
写真 3 (a〜c)　サージタンク128 l，l=10cmの場合



a) 500 r.p.m.

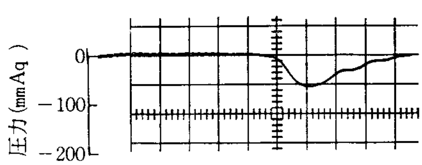


b) 700 r.p.m.

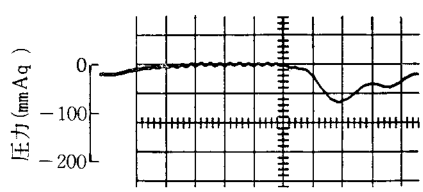


c) 1000 r.p.m.

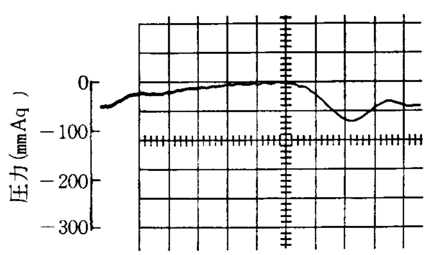
写真 4 (a〜c)　直接，l=2mの場合



a) 500 r.p.m.

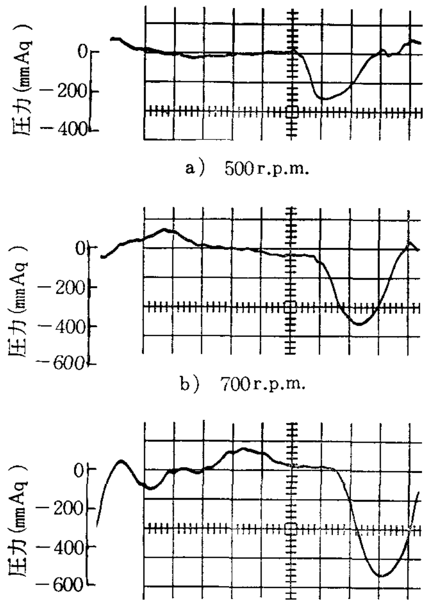


b) 700 r.p.m.



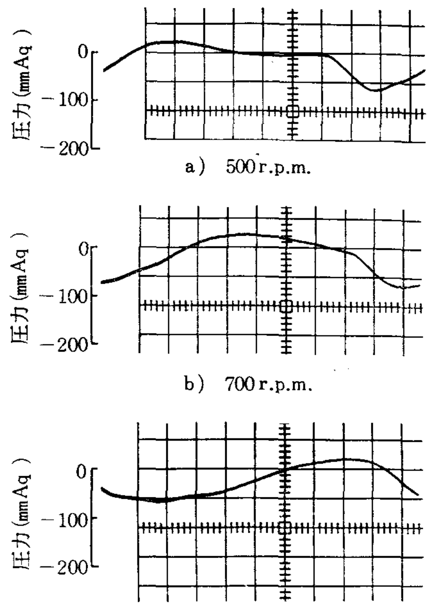
c) 1000 r.p.m.

写真 5 (a〜c)　サージタンク128 l，l=2mの場合



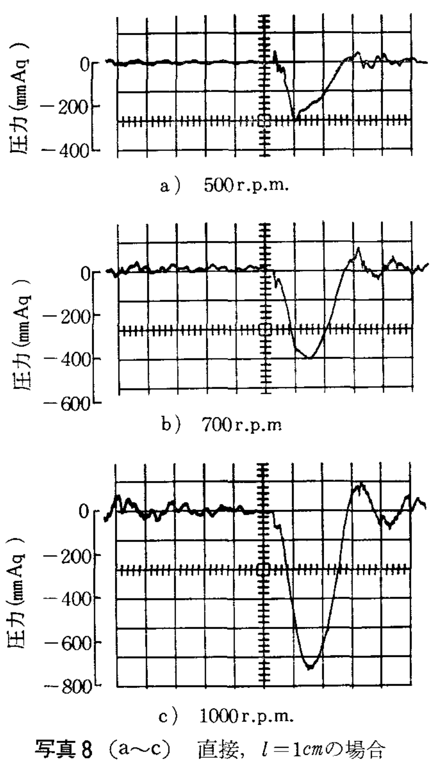
a）　500 r.p.m.
b）　700 r.p.m.
c）　1000 r.p.m.

写真 6（a～c）　直接，$l=10m$の場合



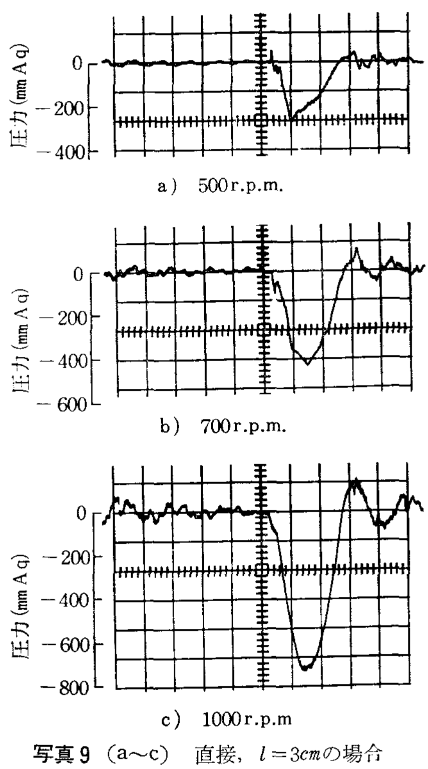
a）　500 r.p.m.
b）　700 r.p.m.
c）　1000 r.p.m.

写真 7（a～c）　サージタンク128 l，
$l=10m$の場合



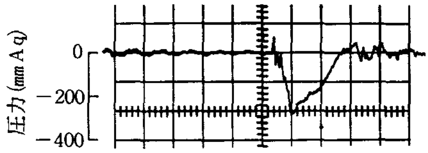
a）　500 r.p.m.
b）　700 r.p.m
c）　1000 r.p.m.

写真 8（a～c）　直接，$l=1cm$の場合

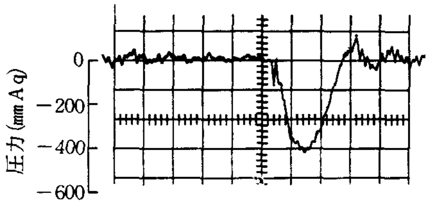


a）　500 r.p.m.
b）　700 r.p.m.
c）　1000 r.p.m

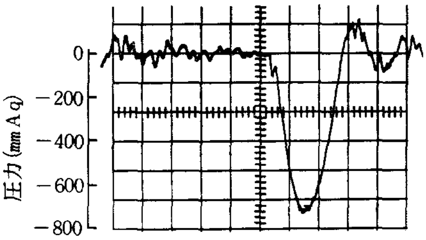
写真 9（a～c）　直接，$l=3cm$の場合



a）500 r.p.m.

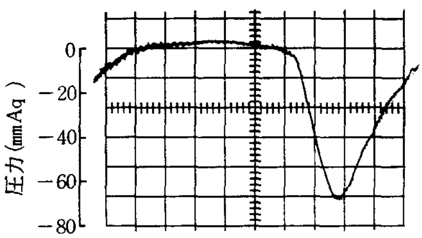


b）700 r.p.m.

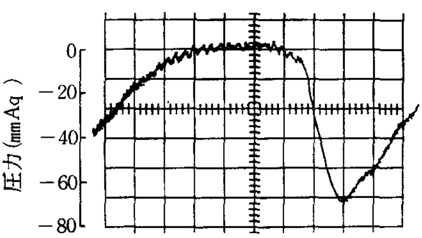


c）1000 r.p.m.

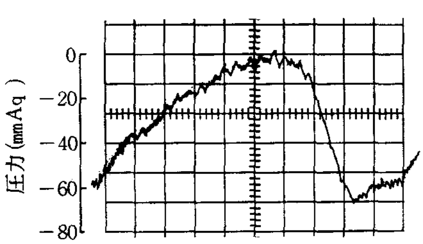
写真10（a〜c）　直接，l＝10cmの場合



a) 500 r.p.m.

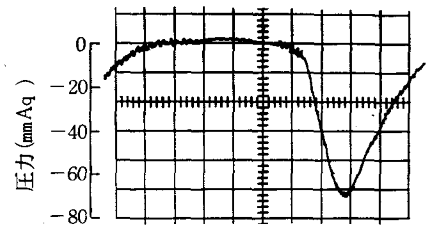


b）700 r.p.m.

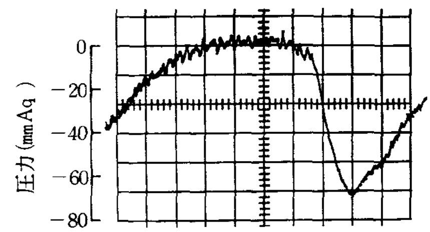


c）1000 r.p.m.

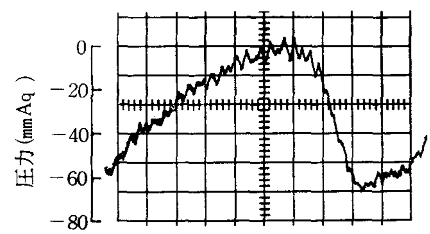
写真11(a〜c) サージタンク128 l，l＝1cmの場合



a）500 r.p.m.

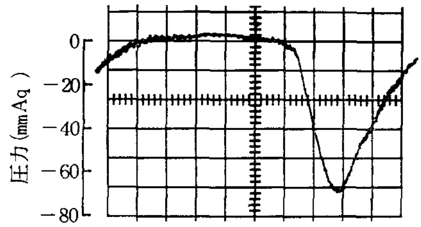


b）700 r.p.m.

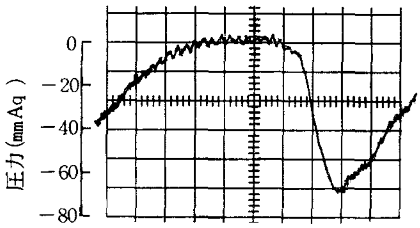


c）1000 r.p.m

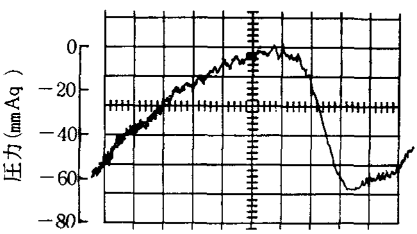
写真12（a〜c）　サージタンク128 l，
l＝3cmの場合



a）　500 r.p.m.

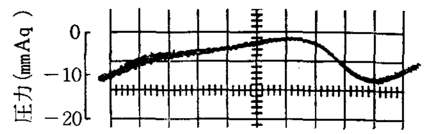


b）　700 r.p.m.

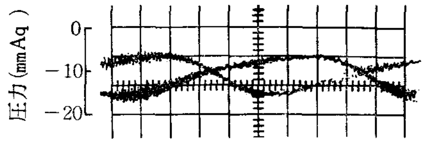


c）　1000 r.p.m.

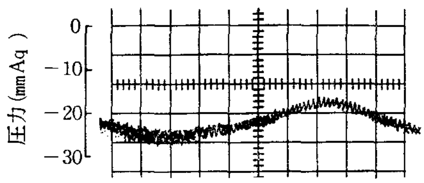
写真13（a〜c）　サージタンク128 *l*，
l＝10*cm*の場合



a）　500 r.p.m..



b）　700 r.p.m.



c）　1000 r.p.m.

写真14（a〜c）　サージタンク（128＋600）*l*，
l＝3*cm*の場合

以上の写真から，下記のことがわかる。

3.1.1　全般的状況

(1)　サージタンクなしの直接測定の場合〔写真2，4，6〕

ⓐ　脈動振幅は非常に大きく，回転数と共に増大してゆく。しかも1サイクル中正圧が発生すること，すなわち逆流が存在することが確認された。

ⓑ　ホース長はやはり波形に影響する。この写真群は *l*＝10*cm*，2*m*，10*m* の場合のものであるが，ホースが長い程，小振幅部の小波はなめらかになる傾向が認められる。これは長い気柱がダンパの効果を与えて，細部の情報を消す結果になるためと考えられる。大きい振幅部に与える *l* の影響は少し複雑で，*l* が長い程振幅が減ると予想したがそうではなく，*l*＝2*m* の場合が振幅最大となっているようである。これは気柱の共振のような現象が生ずるためではないかと思う。

(2)　128 *l* サージタンクを用いた場合〔写真3，5，7〕

ⓐ　直接の場合と較べて最大振幅は著しく小さくなり，かつ小波は消えて滑らかな曲線となり，しかも大波の裾野がひろがり，整流効果が著しい。また回転数による最大振幅の変化も僅少になる。

ⓑ　ホース長の影響としての特徴は，*l*＝10*m* にもなると逆流の大波が発生した形であらわれることである。

ⓒ　しかし，低速では中断度 t/t_0（図2参照）は依然として大きく，1,000r.p.m.でほぼ中断度0になる程度で，128 *l* のサージタン

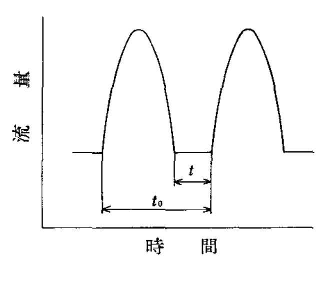


図2　中　断　度

クそのままでは，まだ効果が不十分なことが判る。

(3)　(128l+600l) サージタンクを用いた場合〔写真14〕

上記のようにメーカー納入の 128 l サージタンクでは，脈動防止効果不十分と判明したので，これに 600 l のサージタンクを併用して実験を行った。これによると中断度は0になり，1サイクル中常に負圧となり，脈動が大幅に消えることが判る。ただ波の高低差がまだ相当にあり，完全な定常流は依然得られない。

3.1.2　サージタンクの影響〔写真8～13〕

サージタンクのない場合と，128 l のサージタンクをつけた場合とを比較するために追加した写真であるが，前述したようにサージタンクを用いると中断度が著しく減少し，脈動を消す効果のあることが判る。写真では縦のスケールを変えてあるので，そのまま比較はできないが，サージタンクの使用により振幅も数値的には大幅に減っている。

3.1.3　ホース長の影響〔写真8～13〕

l=10*cm*，2*m*，10*m* 間に波形の差のあることは前述したが，更に l<10*cm* の範囲内で l の影響を見るために，l=1*cm*，3*cm*，および10*cm*のホースを用いて，サージタンクなしの場合と128 l サージタンクを用いた場合とで比較した。これによれば3者の間には全く波形に差がないと言ってよい。すなわち，ホース長は余り長いと波形に影響するが，10*cm*以下での影響はないと見てよいとの結論が得られる。

3.2　脈動におよぼす絞りの影響

以上のように 600 l 程度のサージタンクをとりつけても，そのままでは定常流化の効果はまだ完全ではないことが確認されたので，次に脈動におよぼす絞りの影響を見るための実験を行った。

3.2.1　脈動に関するルッツ[1]の理論の概要および計算

ルッツは脈動の振幅とそれによって生ずる流量誤差との関係を論じ，波形を正弦波と仮定して，この誤差を1%以内に収めるための条件をもとめているが，単シリンダ4サイクル機関の場合につき表2のような数表を示している。

表2　単シリンダ4サイクル機関に相当する誤差率　%

P/V	0.171	0.286	0.571	1.142	1.713	2.86	5.71
$\frac{h_1-h_0}{h_0}$ %	0.0841	0.238	0.949	3.75	8.16	22.7	72.2
$\frac{\Delta Q}{Q_0}$ %	0.042	0.119	0.474	1.87	4.05	10.9	31.3

ただし，Q_0(cc/sec) は1サイクル中の平均流量，ΔQ(cc/sec) は脈動による測定誤差，h_0および h_1 (mmAq) はそれぞれ Q_0 及び ($Q_0+\Delta Q$) に対応する圧力差である。また $V=V_2/(Q_0t_0)$，$P=\bar{P}_2/(P_0-\bar{P}_2)$ で，V_2はサージタンクの容積，t_0は脈動の1周期で，機関の回転数を n r.p.m. とすれば，4サイクルの場合は $t_0=\frac{120}{n}$(sec) となる。$\bar{P}_2$ はサージタンク内の平均圧力，P_0 は大気圧である（図3参照）。

これを用いて，本実験の場合につき計算してみると，次のようになる。

(1)　V_2=128 l の場合

1サイクルに吸入する空気量 Q_0t_0は，容積効率 $\eta_v\fallingdotseq 1$ と仮定すれば，近似的に $Q_0t_0=V_s=1.93\ l$（ただし V_s はエンジンの行程容積）であるから

$$V=\frac{V_2}{Q_0t_0}=\frac{128}{1.93}=66.32$$

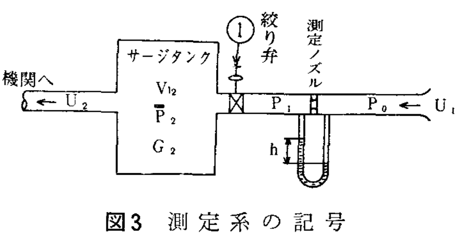


図3　測定系の記号

表2から $\Delta Q/Q_0=0.005$ とすると，$P/V=0.58$ となるので

$$P=0.58\times 66.32=38.47$$

$P_0=1.033\times 10^4$(mmAq) とすると

$$P=\frac{\bar{P}_2}{P_0-\bar{P}_2}$$ より

$$\bar{P}_2=1.00683\times 10^4(\text{mmAq})$$

$$\therefore P_0-\bar{P}_2=261.7(\text{mmAq}) \cdots\cdots (1)$$

すなわち図3において，吸気がサージタンクに流入する間に，絞り弁①を操作して 261.7mmAq 以上の圧力降下を与えれば，吸気脈動は十分に平滑化され，脈動による測定誤差を0.5%以下に抑えることが出来ることになる。

(2) $V_2=(128+600)\,l$ の場合

同様に ($P_0-\bar{P}_2$) を計算すると

$$V=\frac{728}{1.93}=377.2,\qquad P=218.78$$

$$P_0-\bar{P}_2=47\text{mmAq} \cdots\cdots (2)$$

すなわち，この場合は 47mmAq の圧力降下を与えれば脈動防止出来ることになる。ただ本実験では 128 l タンクと 600 l タンクと一体でないので，728 l のタンクとして計算するのは無理かも知れないので，600 l として計算すると

$$P_0-\bar{P}_2=57\text{mmAq} \cdots\cdots (3)$$

となる。

3.2.2 実験結果について

上記のように，脈動を0.5%以内に抑えるために必要な圧力降下 ($P_0-\bar{P}_2$) の理論値が得られたので，サージタンク内の圧力 $\bar{P}_2$ を変化させて実験を行い，上記計算値が果して実際と一致するかどうかを調べた。

(1) サージタンクを使用しない場合

サージタンクの効果と比較するため，先ずサージタンクなしで機関吸気管に直接ノズルをとりつけ，水柱マノメータを用いて平均差圧を測定し，定常流と仮定して次式(4)で流量を計算してみた。ただし絞り弁は全開で，ホース長 $l=10cm$ の場合である。

$$Q_0=c\cdot A\sqrt{\frac{2g}{\gamma}\Delta P} \cdots\cdots (4)$$

c：流量係数$=0.83$，A：ノズル孔面積$=10.18cm^2$，g=重力加速度$=9.8m/\text{sec}^2$，γ：空気の比重量$=1.22kg/m^3$，ΔP：差圧 (mmAq)

それをまとめると表3のとおりである。η_vは機関の容積効率であるが，何れも $\eta_v>1$ となっており流量が過大に測定されていることがわかる。

表3 サージタンクを使用しない場合の流量実測値

回転数 (r.p.m.)	ΔP (mmAq)	$\sqrt{\Delta P}$	$Q_0\times 10^{-3}$ (m^3/sec)	η_v
500	25.0	5.0	16.9	2.10
700	47.5	6.9	23.3	2.07
1000	82.5	9.1	30.8	1.92

(2) 128 l タンクを用いた場合

図1に示した絞り弁③を操作して ($P_0-\bar{P}_2$) を変化させて実験した結果は，写真15に示すとおりで，絞り度が大きくなるにつれて脈動が消えて行き，平坦な定常流となる状況がよくわかる。ただし，500r.p.m. の場合である。

また，このときのノズル前後の差圧，および定常流として式(4)から計算した流量をまとめると表4のとおりである。

(3)　(128+600) l を用いた場合

同様に(128+600) l タンクを用いて，500r.p.m.で実験した結果を写真16および表5に示す。

$P_0-\bar{P}_2>80$mmAqでは $\Delta P=4$mmAq＝一定で，128 l の場合と全く一致し，定常流化の完了を示している。表3，表4及び表5をプロットしたものが図4及び図5である。

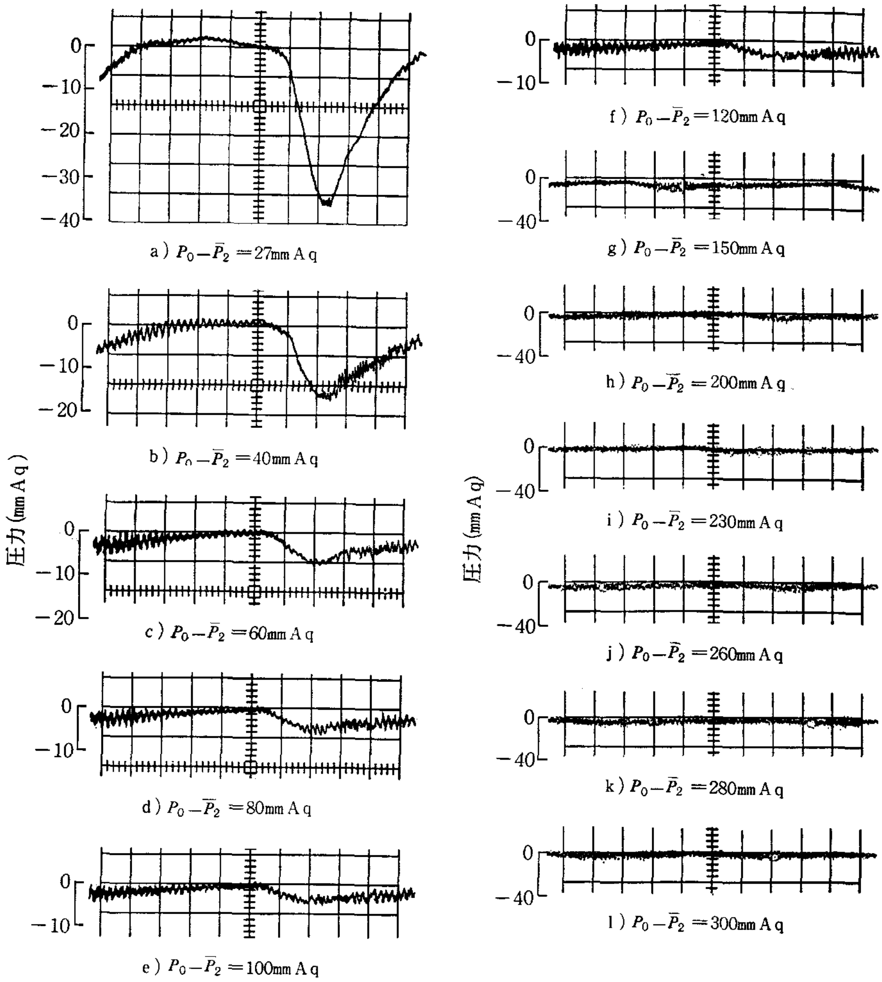


写真15 (a〜l)　サージタンク128 l，$l=3cm$，500 r.p.m.の場合

表4　128 l サージタンクを使用した場合の流量実測値

$P_0-\bar{P}_2$(mmAq)	28	40	60	80	100	120	150	180	200	220	250	280	300
ΔP(mmAq)	13	6.5	5	4.5	4.3	4.3	4	4	4	4	4	4	4
$\sqrt{\Delta P}$	3.6	2.5	2.24	2.12	2.06	2.06	2	2	2	2	2	2	2
Q_0(m^3/sec)	12.16	8.45	7.57	7.17	6.96	6.96	6.76	6.76	6.76	6.76	6.76	6.76	6.76
η_v	1.51	1.05	0.94	0.89	0.87	0.87	0.84	0.84	0.84	0.84	0.84	0.84	0.84

表5　(128+600) l サージタンクを使用した場合の流量実測値

$P_0-\bar{P}_2$(mmAq)	15.3	40	60	80	100	120	140	160	180	200
ΔP(mmAq)	4.4	4.1	4.05	4	4	4	4	4	4	4
$\sqrt{\Delta P}$	2.10	2.02	2.01	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Q_0(m^3/sec)	7.09	6.84	6.80	6.76	6.76	6.76	6.76	6.76	6.76	6.76
η_v	0.89	0.85	0.85	0.84	0.84	0.84	0.84	0.84	0.84	0.84

図4からわかるように，サージタンクを用いないで直接吸気される場合，普通の差圧流量計を用いて流量測定を行うと，η_v は200％前後にもなり，きわめて多量の空気が吸入されているかのように測定される。

図5から判ることは128 l のサージタンクを用いても，そのままでは依然 $\eta_v=150$ ％と大きく測定されるが，絞り弁を操作してタンク内圧を下げると脈動は急激に減少し，$P_0-\bar{P}_2>150$mmAq となれば $\eta_v=84$ ％で一定となる。

(128＋600) l のサージタンクを用いれば，絞り弁全開のままでも $\eta_v=89$ ％となり，128 l サージタンクにおいて80mmAq まで絞った時と等しい値が得られ，$P_0-\bar{P}_2>80$mmAq では $\eta_v=84$％ で一定となる。

これを要するに，いずれの場合でも，ある程度の圧力降下を与えれば，それ以上絞っても η_v は変化せず一定値を示すようになる。一方写真15，16を見れば η_v が一定となったときの波形は殆ど平坦化が完了して，絞り度とは無関係に一定の定常流を示すことがわかる。表2をグラフにすると図6を得るが，これから見ても P/V が

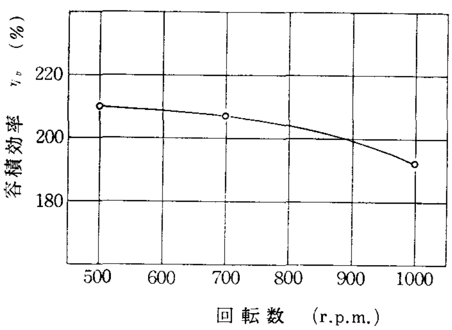


図4　容積効率と回転数の関係
（サージタンクを使用しない場合）

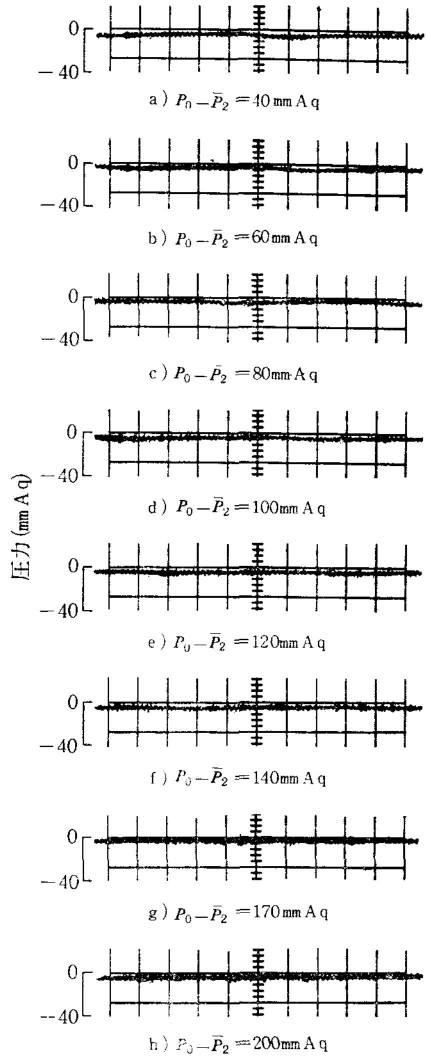


写真16 (a〜h)　サージタンク(128＋600) l，
$l=3cm$，500r.p.m. の場合

ある程度小さくなると，つまり絞り度をいくら大きくしても変動誤差 $\Delta Q/Q_0$ の変化は極めて小さくなり，ルッツの理論と実際とは，定性的にはよく一致しているようである。$P_0-\bar{P}_2$の値が理論値と実験値で一致しないのは，ルッツの設けた正弦波としての仮定および $\eta_v=1$ との仮定にもとずくものと思われる。

(4)　多シリンダ高速ガソリン機関の場合の脈動

更に参考のため，回転数の非常に高い多シリンダ機関の場合として，ガソリン機関を用いて波形をしらべてみた。ガソリン機関の要目は表6のとおりである。この機関をモータリングして，気化器の絞り弁全開の場合につき実験した。

サージタンクを用いないで実験した場合の結果を写真17，表7及び図7の曲線①に示す。これによれば多シリンダ高速ガソリン機関でも，サージタンクを使用しなければ，非常に大きい振幅の波が発生して，脈動は消えないようである。ただ，大波の平均高さは，水平直線となるようである。

写真18，表7及び図7の曲線②は128 l のサージタンクを使用した場合であるが，小波の振幅は極め

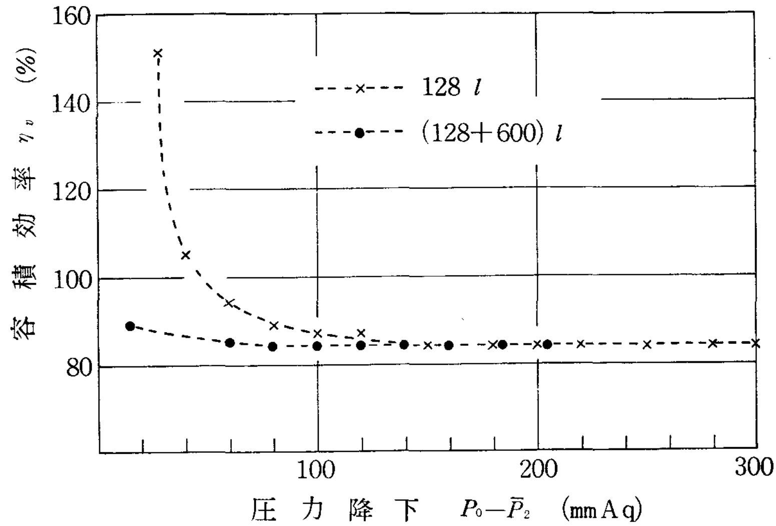


図5　容積効率と圧力降下の関係（サージタンク使用の場合）

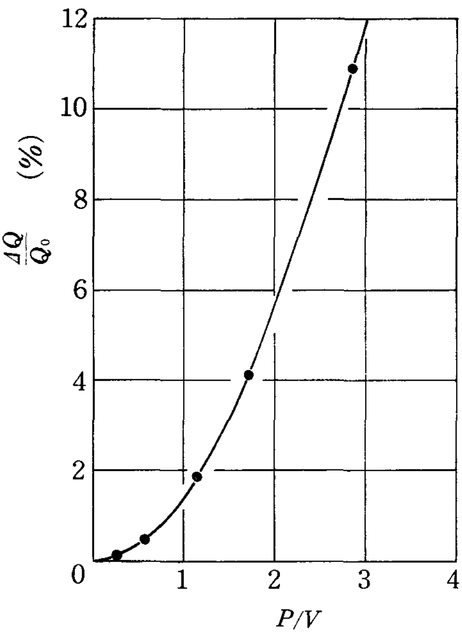


図6　単シリンダ4サイクル機関に相当する場合の誤差率特性曲線

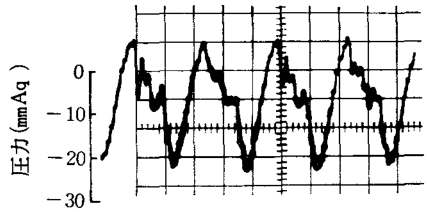
表6　ガソリン機関の主要目表

項　　目	内　　容
サイクル・シリンダ数	4サイクル・4気筒
配　　列	直　　列
内径×行程（mm）	ϕ70 × 68
総排気量（cc）	1046
圧　縮　比	8.0
定格出力（PS/r.p.m.）	26.5 / 3200
圧縮圧力（kg/cm^2/r.p.m.）	10.5 / 400
弁　配　直	頭上弁式
点火順序	1—3—4—2
冷却方式	水冷強制循環式

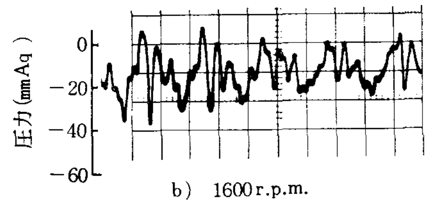
て小さくなると同時に大波の平坦化が認められ，定常流化が著しい。ただ，3200r.p.m.では小波がかなり激しい。

図7の曲線①②の特性の解釈にはなお詳細な検討を要するけれども，写真18とディーゼルの定常化の場合の波形とを比較して判断すると，128 l サージタンクを使用すれば，絞り弁なしでも2400r.p.m.までは定常化され，更に絞りを実施すれば3200r.p.m.の定常化も可能と思われる。

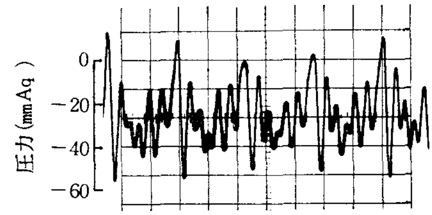
試みに，この場合のサージタンクの条件をルッツの理論で計算してみれば，次のようになる。ルッツによると4サイクル・4シリンダ機関の場合は次式が成立する。



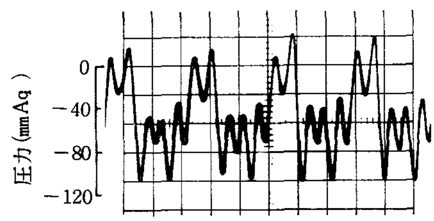
a) 800 r.p.m.



b) 1600 r.p.m.



c) 2400 r.p.m.



d) 3200 r.p.m.

写真17 (a～d) ガソリン機関，直接，$l=3cm$の場合

表7 ガソリン機関の流量実測値

条件	回転数 r.p.m.	ΔP mmAq	$\sqrt{\Delta P}$	$Q_0\times10^{-3}$ (m^3/sec)	η_v
直接測定	800	0.5	0.71	2.39	0.34
	1600	4.5	2.12	7.17	0.51
	2400	19	4.35	14.73	0.70
	3200	45	6.71	22.67	0.81
128 l タンク付	800	0.5	0.71	2.39	0.34
	1600	4.5	2.12	7.17	0.51
	2400	14	3.74	12.65	0.60
	3200	29.5	5.43	18.36	0.66

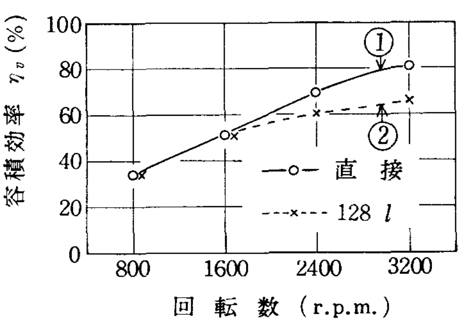
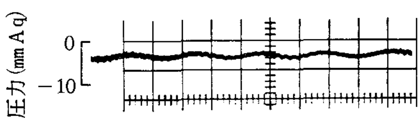
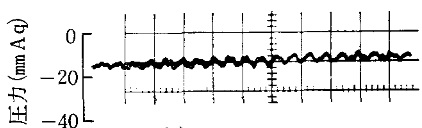


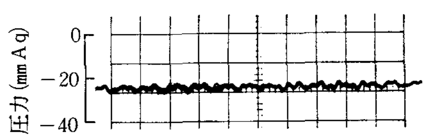
図7 容積効率と回転数との関係
(ガソリン機関の場合)



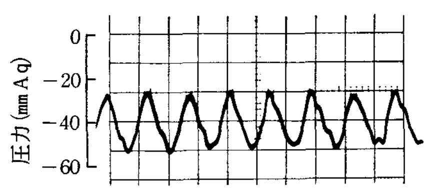
a) 800 r.p.m.



b) 1600 r.p.m.



c) 2400 r.p.m.



d) 3200 r.p.m.

写真18 (a～d) ガソリン機関，128 l，$l=3cm$の場合

$$\frac{\Delta Q}{Q_0}=\frac{1}{4\left[1+\left(\frac{4\pi}{\kappa}\times\frac{V}{P}\right)^2\right]} \quad \cdots\cdots(5)$$

ただし　κ：空気の比熱比

$\Delta Q/Q_0=0.05$，$\kappa=1.4$ とすれば，上式より $V/P=0.79$ で，本実験機関は気筒容積1046ccであるから，$\eta_v=1$ として

$$Q_0 t_0=\frac{1.046}{4}=0.262\,l$$

$V_2=128\,l$ とすれば

$$V=\frac{V_2}{Q_0 t_0}=\frac{128}{0.262}=489$$

$$\therefore P=\frac{V}{0.79}=\frac{489}{0.79}=618$$

$$\therefore P_0-\bar{P}_2=\frac{1.033\times10^4}{618}=16.70\,(\mathrm{mmAq}) \quad \cdots\cdots(6)$$

$P_0-\bar{P}_2$ は今の場合実測しなかったが，ディーゼル機関データ表4から，$128\,l$ のサージタンクを用いて，バルブ全開で500r.p.m. のときの $P_0-\bar{P}_2=13$mmAq であるから，高速多シルンダの本ガソリン機関では，$P_0-\bar{P}_2>16.70$mmAq の条件は満足していると推測して間違いないであろう。すなわち，絞りを与えなくても，定常化は十分行われていると見てよいであろう。

§4　結　　言

内燃機関の吸気の脈動について研究した結果をまとめると次のとおりである。

1．単シリンダ低速機関の場合

(1) 脈動を消すためには，サージタンクは絶対不可欠である。

(2) サージタンクを使用した場合，吸気系に絞り弁を設けて，回転数に応じた絞りを与えると定常流化には非常に効果的である。絞りを用いないと非常に大型のサージタンクが必要である。

(3) 波形は機関回転数，絞り度のほか測定系のホース長などの諸要因によって変化し，波形と諸要因との関係が明らかとなった。

(4) ルッツの理論は，定性的にはよく実状と合致するが，定量的には必ずしも一致しない。これはルッツの理論で設けた仮定と実際との差によるものと思われる。

2．多シリンダ高速ガソリン機関の場合

(1) この場合でも，サージタンクは絶対不可欠である。

(2) 単シリンダ低速機関の場合よりも，サージタンクは小型ですむ。ただ単シリンダの場合と逆に，高速回転になるほど，絞りを増す必要があると推定される。

参　考　文　献

(1) O. Lutz : Gasmengenmessung bei Kolbenmachinen mittels Düsen und Blenden, Ingenieur Archiv, Band III. (1932)

（昭和52年5月30日受付）

色温度による店舗照明の考察

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A Study in Lighting for Merchandising by Color Temperature

Kazuhiko HARADA

It is needless to say that lighting for merchandising must be sufficiently bright and agreeable, if we want to improve the financial results of sale. Therefore, the character of light, control of color temperature is foundamentally one of the most important factor.

So, we did investigation on that subject at the store in Okayama, Fukuyama, Kure, Hiroshima and Matsuyama city.

According to the statistics, for the most part, using incandescent lamps with fluorescent lamps or only incandescent lamps.

There was a tendency that the newer stores and the higher-class stores, the more use of incandescent lamps.

The color temperature were from 2,850K to 4,350K under the influence of incandescent lamps' lighting.

Relatively bag stores and shoes stores were low color temperature but dry goods stores were high one.

§1　緒　　言

店舗照明は，ディスプレイ照明と言えばすぐに店舗照明が頭に浮んでくるほど，我々の日常生活に融和している感がある。しかも，休むことなく時代の感覚を素早くキャッチしながら進歩，発展を続けている。販売成績を向上させるため，店舗内外及び商品を明るく見せて，快適なふんい気にし，また，その地域全体のディスプレイや照明を調和させて地域ぐるみの繁栄を図ることが必要である。古い都市で，老舗の商店街が廃れて新興の商店街が栄えるという現象がよくあるが，それは，これらのことに積極的に取組まなかったために起ることが多い。現在の商品は，全国的に共通な品物が多く，以前のような地域的な差はあまり見られない。また，流行の変化のテンポも早く，購買層も若年層にウエイトが移りつつある。

こうしたきびしい条件下で販売成績を向上させるには，店舗照明は重大な要素となってくる。購入の目的をもって来る人，又は，一般通行者に足を止めさせて，ショーウインドやショーケース内の商品に注目，記憶をさせ，さらに購売欲を刺激するという一連の動きを滞りなく行わせるには，明るい快適な照明をすることは必要なことであるが，光の質，すなわち，色温度をどの程度にするかが重要なポイントとなってくる。光源も，従来のけい光ランプ一辺倒から，最近は白熱電球やよう素電球が見直されてきている。

本研究は，岡山，福山，呉，広島及び松山の５都市における繁華街の店舗照明について，色温度を中心として調査，検討を試みたものである。

§2　色温度と店舗照明

店舗照明の目的は，広義のディスプレイ照明と同様に注意，興味，欲望，記憶及び行動の5つの要素に分けられる[1]。アメリカのある心理学者は，人間の感覚のうち，視覚を87％と評価しているが，快適な照明効果により視覚に訴えることは最も効果的なことである。暗い光景よりも明るい光景が印象深く記憶に残るように，明るい照明は店舗照明に不可欠のものであるが，単に高照度，多灯形が最良ではなく，光の質を考慮しなければならない。図1[2]に示すように，色温度が低い光源で照度を高くすると暑苦しく感じ，逆に色温度の高い光源で照度が低いと陰うつな感じとなる。

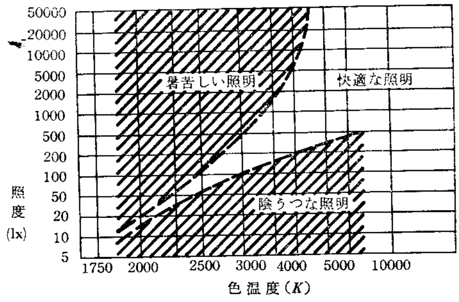

図1　光色と照度によるふんい気

表1[3),4),5)]は各種光源の色温度であるが，約3,200K～4,400Kの範囲が購買性のある色温度とされている。図1から，白熱電球では約100lx～500lxが快適適な照明となり，けい光ランプでは約200lx～10,000lxとなることるがわかる。

戦後，けい光ランプの急速な進歩，普及によって，我々は時間，場所，目的及び対称物等を問わず，けい光ランプの光色に慣らされた感がある。このことは，人間の感情や心理を無視し，生活のリズムを乱していると言っても過言ではない。この反省については，店舗照明についても反映し，けい光ランプを使用した光天井で代表される色温度の比較的高い高照度の照明方法から，やがて，色温度の低い白熱電球やよう素電球が併用，又は単独使用されだしてきた。これによって，高照度を必要とせず適当な照度で，既に述べたような購買性のある範囲の色温度となる。また，適度な輝度により商品を美しく見せ，暖かみのあるふんい気を作ることによって購買力を高めるのに有効となっている。たとえば，貴金属，宝石類は光沢を増し，皮革製品には暖かい感じを与え，食品は新鮮さを表現する。

漸次，店舗の売上げは，午後の明るい時間帯になりつつあるが，このことは，従来の夜間を対象とした照明から，自然光を加

表1　各種光源の色温度

光源の種類	色温度〔K〕
太陽　日出後　30分	2,400 ～ 2,650
〃　　〃　　40分	2,750 ～ 3,100
〃　9時 ～ 15時	5,450 ～ 5,800
〃　15時半頃	4,000 ～ 5,000
〃　正午	5,000 ～ 6,000
〃　北方・空光	6,500
青空の光（9時～15時）	12,000 ～ 26,000
一様に曇った空	6,800 ～ 7,000
月光	4,100
真空電球（タングステン）	2,400 ～ 2,650
ガス入タングステン電球（40W）	2,760
〃（100W）	2,865
〃（500W）	2,960
〃（1000W）	2,990
〃（1500W）	3,025
昼光電球	3,500
けい光ランプ（昼光色）	6,500
〃（白色）	4,500
〃（温白色）	3,500
〃（自然色）	6,500
〃（自然昼白色）	5,000
〃（自然白色）	4,500
〃（高忠実自然昼白色）	5,000
〃（高忠実自然白色）	4,200
〃（高忠実自然温白色）	2,700
ハロゲン（よう素）電球（100W）	2,850 ～ 2,900
〃（150W）	〃
〃（250W）	2,950
〃（500W）	2,980 ～ 3,000
メタルハライドランプ（D―400）	5,000
水銀ランプ（HF―400）	3,800
〃（H―400）	5,800

味した昼間のその店舗に適したディスプレイ照明を考慮すべきであることを意味する。ここでも，適正な色温度値は大切な要素となってくる。

§3　予　備　実　験

実際の店舗を調査する準備として次のような予備実験を行った。男性用皮靴，ネクタイ，時計及び果物の4種類を，けい光ランプと白熱電球の併用又は単独使用で，全般照明，局部照明及び局部全般照明をした。それを，年配男子，同女子，及び青年男子，同女子各5名ずつの被験者に，印象の残る，買いたくなるような見え方について5段階評価をさせた。0.9*m*×0.9*m*×1.8*m* の大きさで，内面を白色ラッカーで塗装した箱に前記の4種類の品物を入れて，照度を 800*lx*±10*lx* に保ちながら照明方法を変えた。照度は，東芝照度計ＳＰＩ-1形を，色温度はミノルタカラーメーターを使用して測定した。

表2は，最も好ましい（印象に残る，買いたくなるような）と判断された照明方法と色温度を示したものである。この実験によって次のようなことがわかった。

表2　最も好ましいと評価された照明方法と色温度

被験者	対称物／照明方法・色温度	靴	ネクタイ	時計	果物
年配男性	全般照明の光源	白熱電球	けい光ランプ（高忠実自然白色）	けい光ランプ（自然白色）	けい光ランプ（高忠実自然白色）
	スポットライトの有無	有	有	有	有
	色温度	2,900*K*	4,050*K*	3,400*K*	3,200*K*
年配女性	全般照明の光源	白熱電球	けい光ランプ（高忠実自然白色）	けい光ランプ（自然白色）	けい光ランプ（高忠実自然白色）
	スポットライトの有無	有	有	有	有
	色温度	2,900*K*	3,950*K*	3,350*K*	3,200*K*
青年男性	全般照明の光源	白熱電球	けい光ランプ（高忠実自然昼白色）	けい光ランプ（自然白色）	けい光ランプ（自然白色）
	スポットライトの有無	有	有	有	有
	色温度	2,930*K*	4,100*K*	3,450*K*	3,300*K*
青年女性	全般照明の光源	白熱電球	けい光ランプ（高忠実自然昼白色）	けい光ランプ（自然色）	けい光ランプ（自然白色）
	スポットライトの有無	有	有	有	有
	色温度	2,950*K*	4,150*K*	4,230*K*	3,350*K*

年配層は，男・女性ともに落着いた照明で，色温度も低い方を好む。若い女子も軟かい照明に好感を寄せるが，好みの色温度は高い。青年男子は力強い照明で，若い女子よりもやや低い色温度を好む。色温度の範囲は，2,900*K*～4,200*K*にあり購買性のあるといわれる色温度の低い方の値であった。

照明方式別では，靴を除いて，けい光ランプで全般照明をし，対象物を白熱電球のスポットライトでアクセントをつける局部全般照明が一般的に好評であることがわかった。しかし，靴は皮革特有の暖かさが好まれるため，色温度の低い白熱電球による照明が好印象を与えるようである。

実際には，商店街及びその店舗全体のふんい気，店内外のディスプレイ，人の流れや音楽による効果等の影響で条件が違う。したがって，以上の予備実験の結果は一応の目安と考えるべきであろう。

§4　調査及び考察

店舗の1年中で一番大切な時期は年末で，ディスプレイもそれに合せて豪華で充実したものになる。岡山，福山，呉，広島及び松山の繁華街の店舗とデパートについて，この時期で，時刻は午後2時から午後4時頃までの最も人出の多いときに調査を行なった。

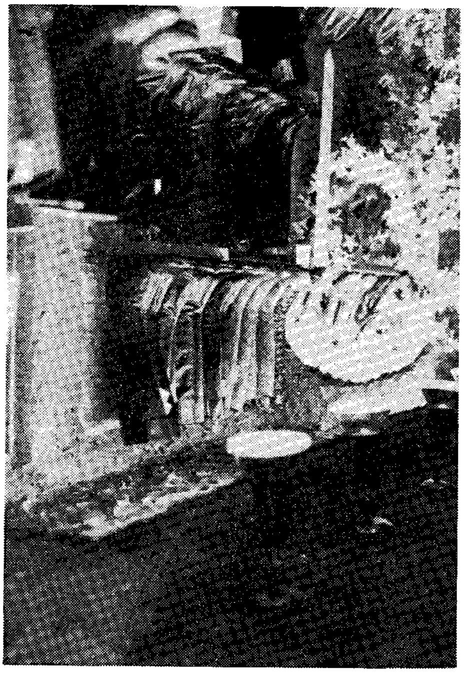

写真1(A)　照度　610 lx　色温度　2,850K

4・1　靴　　　店

写真1（A）は，白熱電球のスポットライトだけで照明している。天井，壁面は暖色で暖かい感じを与え，スポットライトで商品の材質感を出し，光沢を持たせ，かつ，全体を柔らかいふんい気で包んでいる。**写真1**（B）もホワイトボール電球だけで照明し，スポットライトも使用せず店内を暖かいムードにしている。ショーウインドだけはアクセントをつける意味で 3,800 K程度にしている店はあったが，ほとんどは電球だける照明で 3,000 K以下の色温度が多かって。

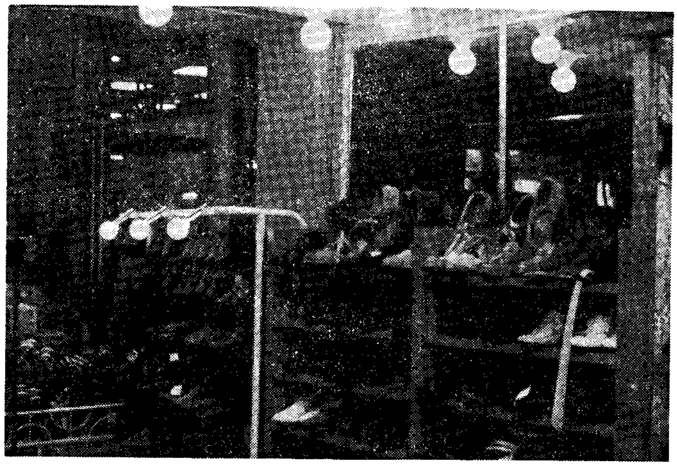

写真1(B)　靴　店　照度　800 lx　色温度　2,890K

4・2　鞄　　　店

茶，黒色系統の商品が冬季であるため多い。**写真2**も，けい光ランプは一部だけでほとんどダウンライトとスポットライトを使用している。したがって，靴店同様色温度は低い。スポットライトの効果で材質感がよくでていて，触れてみたくなるような感じをだしている。

写真2　鞄　店　照度　740 lx　色温度　2,910K

4・3　呉　服　店

写真3（A）は，高忠実自然昼白色けい光ランプと白熱電球の併用であるが，婦人呉服の鮮かな色を屋外の自然光と同程度の色温度にして，屋外で見るのと同じような効果をあげている。**写真3**（B）は，日

本調のけい光灯器具に高忠実自然白色けい光ランプを使用して，色を正しく見せることに努力し，呉服特有の柔らかさを強調しながら，白熱電球で立体的なアクセントをつけている。一般に，呉服店の色温度は高く，4,300*K* 近いものも多かった。

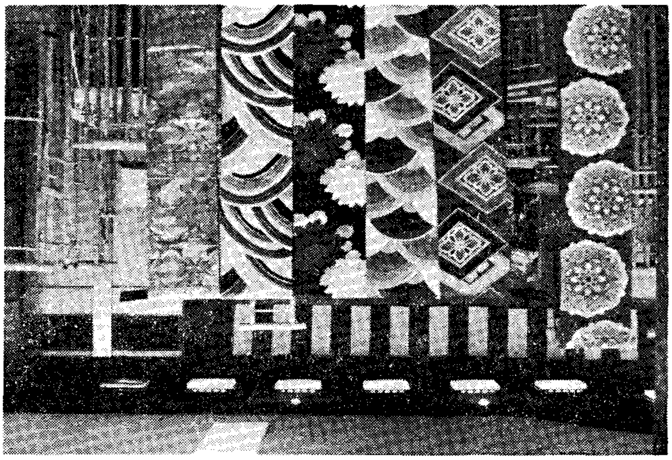

写真 3 (A)　照度 1,200 *lx*　色温度 4,350*K*

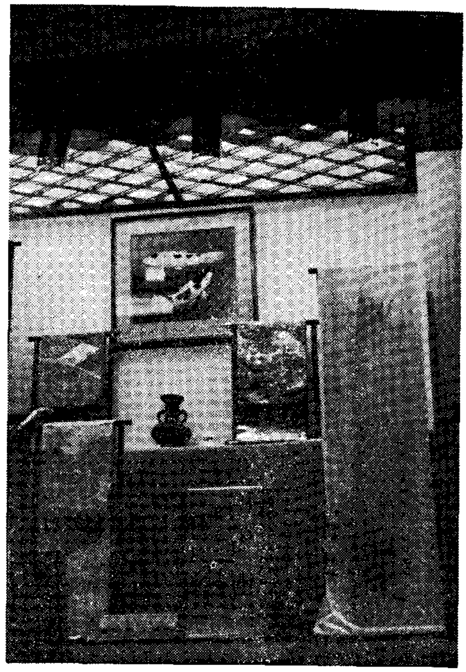

写真 3 (B) 呉服店 照度 1,100 *lx* 色温度 4,230*K*

4・4 婦人服店

白色けい光ランプで全般照明をし，棒状の白熱電球用器具を使用して女性向きのふんい気を出しているのが**写真 4 (A)**である。ブラケットを使用しているが，スポットライトを使っていないので照度がやや低いが，服地のディスプレイにはよくマッチしている。**写真 4 (B)**は(A)と対象的で，白熱電球とよう素電球のスポットライトで高照度として最新流行の服をディスプレイしている。漸新な感覚がよくでている。普段は，全部のランプは点灯しない由であった。電球だけの照明であるから色温度は低い。3,500*K* を越す例はあまりなかった。スポットライトのランプの大きさを変化させて，商品に違った感じを持たせるようにした店舗があった。

写真 4 (A) 照度 350 *lx*　色温度 3,150*K*

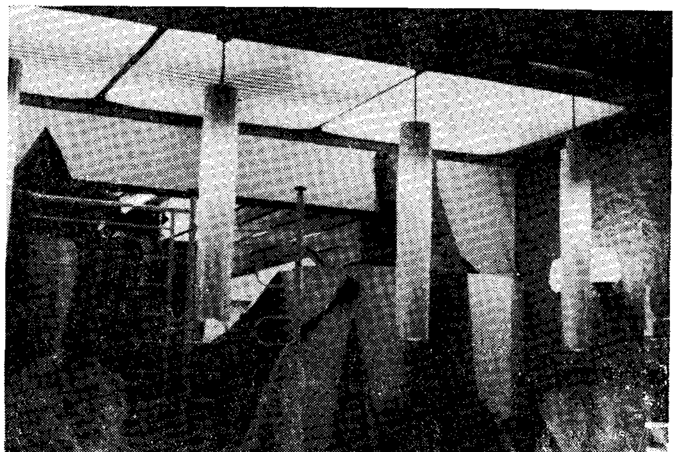

写真 4 (B) 婦人服店　照　度 4,300 *lx*
色温度 2,900 *K*

4・5　紳　士　服　店

写真5は，ともに白色けい光ランプで全般照明をし，白熱電球でアクセントを持たせている。（**A**）では，ろうそく形電球をアクセサリー的に使用し，（**B**）では，シャンデリアで豪華な感じを出している。演色性を重視した呉服店に比べて，重厚さを強調している。冬服を対象にしているので，色温度は低い。

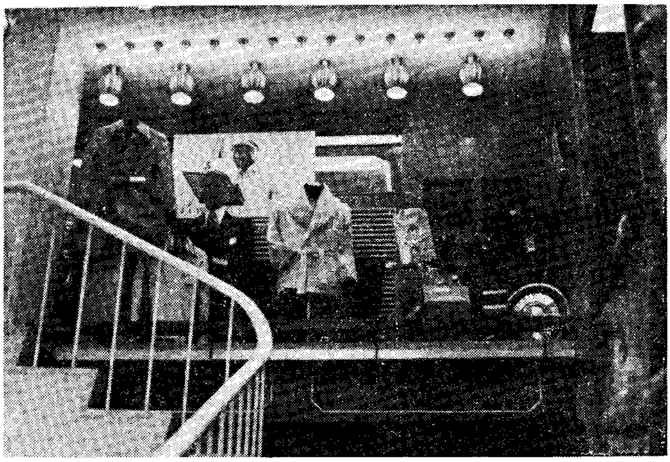

写真5(A)　照度　450 *lx*　色温度　2,950 *K*

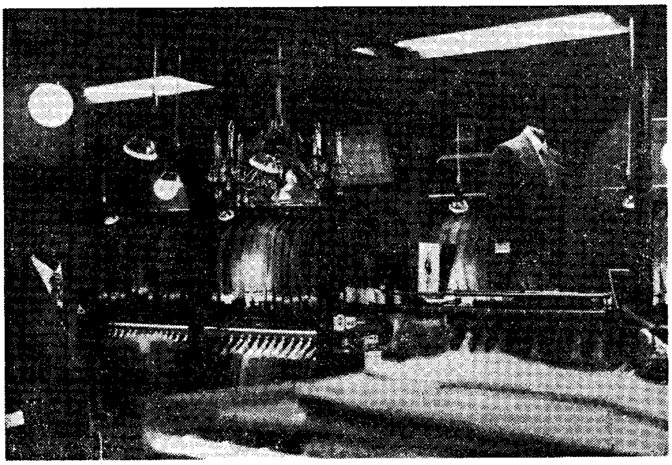

写真5(B)　紳士服店　照度 800 *lx*　色温度 3,070 *K*

4・6　貴金属店・宝石店

高照度で貴金属や宝石を照明するのが一般的であるが，熱の影響を受ける宝石もあるので，けい光ランプで明るい全般的照明をし，ダウンライトやスポットライトで輝度を高める方法が多い。色温度はやや高い。

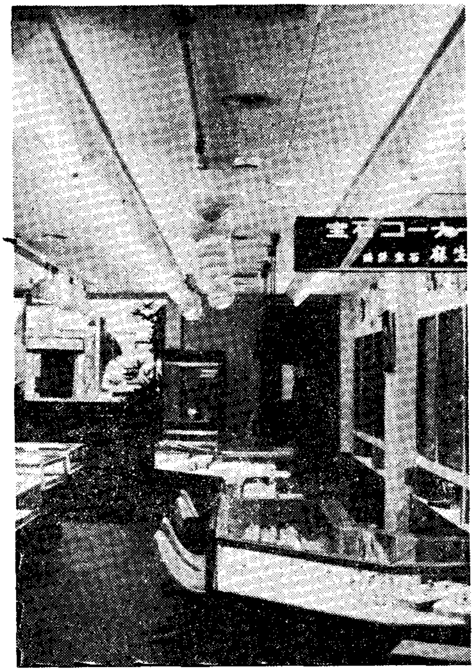

写真 6(A)　照度 950 lx　色温度 3,640K

写真 6(B)　貴金属・宝石店　照度 1,200 lx　色温度 3,650K

4・7　陶　器　店

けい光ランプと白熱電球の併用が一般的である。**写真 7** もその例で，（B）では，スポットライトを下方に向けて照度を上げ，さらに色温度を上部に比べて低くして落着きを出している。陶器の持つ光沢もよくでている。したがって，色温度は一定していない。

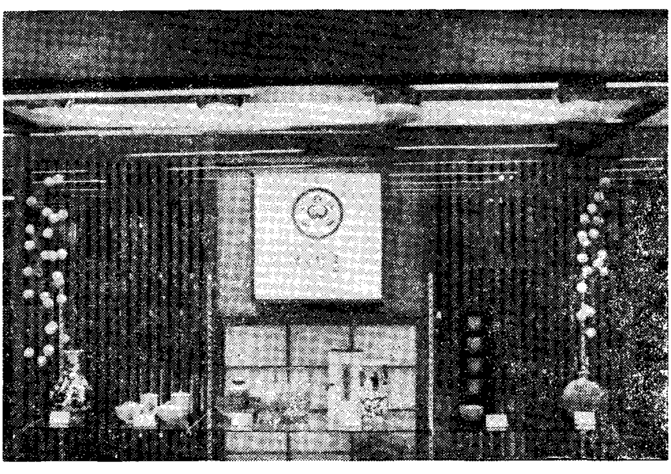

写真 7(A)　照度 1,450 lx　色温度 3,200K

写真 7(B) 陶器店 照度 800 lx 色温度 2,980K

4・8 眼 鏡 店

写真8は，白熱電球だけのフットライトによる特殊な照明方法である。眼鏡や枠が透けて見えるようになっているが，材質が，透明又は半透明の商品には効果のある手法である。店内は，けい光ラスプだけで高照度にした店舗が多いので，使用ランプの色温度でほとんど値が決まる。4,500*K* 前後が多い。

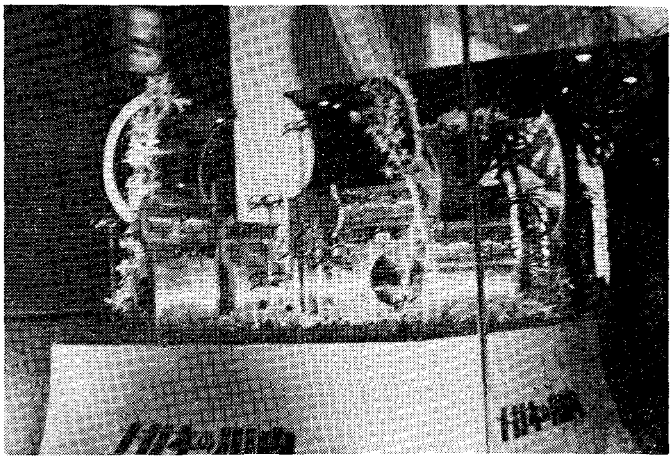

写真8 眼 鏡 店 照度 590 *lx* 色温度 2,900*K*

4・9 酒 店

後方から乳白色のガラスを通してけい光ランプで照明し，洋酒の瓶を浮び出させるようにして形の面白さを強調している。瓶の凸凹部分も透けて見える。前方の上方から白熱電球のスポットライトを使用している。照度も色温度も比較的低い値である。全店内の全般照明には，けい光ランプを使っている店舗がほとんどである。

写真9 酒店 照度 400 *lx* 色温度 3,070*K*

表3は，今回調査した代表的店舗の商品別の色温度を示したものである。けい光ランプだけによる照明はほとんどなく，けい光ランプで全般照明をし，白熱電球のダウンライトやスポットライトを局部照明として使用する方法が多く，一部では，白熱電球やよう素電球だけを使用していた。最新の店舗や高級品店では，電球だけの使用が多い傾向にあった。冬季のディスプレイであるためもあろうが，白熱電球の使用量が多いため色温度は予想していたよりも低く，2,850*K*～4,350*K* の範囲であった。なかでも，靴・鞄など皮革製品を扱う店舗は，2,900*K* 程度で皮革の持つ暖かみ，光沢や材質感を出すのに成功している。対称的に色温度の高かったのは呉服店で，呉服の鮮かで繊細な色彩を自然光に近い条件下で品定めをすることは大切で，高演色性のけい光ランプを使用し，スポットライトの使用量が少ないのでこの結果となる。しかし，日没後のショーウインドの照明を白熱電球だけにするという店舗があった。全般的に白熱電球（一部よう素電球）の使用量が増加しており，かつてのけい光ランプ万能の照明方法は，過去のものとなっている。

予備実験の結果と実際に調査した結果は，大差なく傾向が同じであることがわかった。

地域による差はあまり見られなかったが，松山の店舗で白熱電球の使用の多いのが目立った。

省エネルギー時代に逆行して，店舗照明は消費電力の多い白熱電球やよう素電球の使用量が増加しつつあるが，**図1**によれば，色温度が低下すれば快適な照度も下がるので，販売のために必要な照明は維持しながら，節電に留意することが大切である。

表3　代表的店舗の商品別の色温度

商品	色温度(K)	地域	備考
靴	2,880	広島	
〃	2,950	〃	
〃	2,850	岡山	
〃	2,900	松山	
〃	2,890	〃	
〃	3,250	呉	ショーウィンド
鞄	2,870	呉	
〃	2,930	福山	
〃	2,910	岡山	
婦人服	3,430	岡山	ショーウィンド
〃	3,250	広島	
〃	2,980	松山	
服地	3,150	福山	
〃	3,310	呉	
セーター	3,050	広島	
〃	3,210	呉	ショーウィンド
紳士服	2,980	松山	
〃	2,950	呉	
ネクタイ	3,580	岡山	
〃	3,860	福山	
呉服（女物）	4,200	呉	
〃	4,350	広島	
〃	4,230	岡山	
〃	4,600	松山	
時計	3,450	呉	
〃	3,920	広島	ショーウィンド
〃	3,860	岡山	
宝石	3,940	福山	
〃	3,510	松山	
〃	3,640	広島	
アクセサリー	4,450	福山	
〃	4,070	岡山	
陶器	3,020	呉	
〃	2,980	広島	
果物	3,050	呉	
〃	3,120	広島	
眼鏡	2,900	松山	ショーウィンド
〃	4,500	広島	

§5　結　言

5都市の店舗照明の実際について色温度を中心に調査したが，各店とも工夫を凝らし，人間性を重視した照明で，現在の照明技術から判断すれば，かなりの努力がなされていることがわかった。機会があれば，他の時期に，さらに調査の範囲を拡げたい。

終りに，年末の多忙中であったにもかかわらず測定に協力，激励して下さった店舗の責任者，卒業研究として測定をしていただいた本校9期生貞森公之，広兼恭治君に厚く感謝する。

参考文献

1) 東宮　傳：ディスプレイ照明ハンドブック
2) 照明普及会：店舗照明の実際
3) 電気学会：照明工学
4) 東芝：照明器具カタログ
5) 松下電工：ナショナル照明器具カタログ

（昭和52年5月31日受付）

コンクリート杭の内部摩擦について

（土木工学科）　久　良　喜代彦

The Internal Friction of a Concrete Pile

Kiyohiko KURO

The attenuation factors of mortar bars were measured by the free vibrations method.

Then, characteristics of the damping models such as the Voigt type, the Maxwell type and the three elements type were studied.

Especially the adaptability of the Voigt solid to analyze the damping of the driving stress waves of a concrete pile was examined.

§1　まえがき

杭打ち時に杭頭に発生する高歪圧縮波はある応力度段階まで急速に減衰し，それ以後はあまり減衰しないものと思われる[1]。しかし，引張応力の評価の立場から言えば，通常の応力段階の応力波の減衰について無視出来ないものであるように思われる[5]。

本研究は後者の場合の応力波の減衰に関連して行うもので，研究の目的は次の通りである。

i　自由振動法によってモルタル棒の減衰定数を測定する。

ii　内部摩擦を表わす各種の減衰モデルの特性について比較検討する。

iii　特に Voigt 型モデルの適用性について調査する。

§2　記　号

本報告の中で用いられる記号の主なものは次のようなものである。

c	応力波の伝ぱ速度	n	振動数
E	弾性係数	ρ	密　度
$f=2\pi/\lambda$		σ	応　力
$p=2\pi\cdot n$	円振動数	t_1	応力波の立上り時間
t	時　間	τ'	遅延時間
u	x 方向変位	τ	緩和時間
α	応力波の減衰定数	η	粘性係数
ε	ひずみ	Δ'	対数減衰率
λ	波　長		

§3　減衰定数及び対数減衰率

不完全弾性の棒を伝ぱする応力波が打撃端から x だけ進行したときの応力振幅 σ を

$$\sigma=\sigma_0\cdot\exp(-\alpha\cdot x) \qquad (1)$$

σ_0：打撃端に加えられた応力

と表わすとき，x の係数 α は減衰定数と呼ばれる。この時，（1）より

$$\alpha=-\frac{1}{x}\cdot\log\frac{\sigma}{\sigma_0} \qquad (1)'$$

一方，自由振動で引き続いて生ずる振幅の比の自然対数は対数減衰率と呼ばれる（**図 1**）。

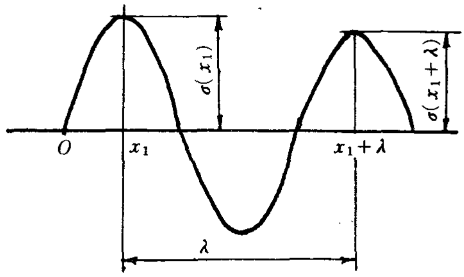

図 1

つまり，

$$\Delta'=-\log\frac{\sigma(x_1+\lambda)}{\sigma(x_1)}=-\log\frac{\sigma(x_1+c/n)}{\sigma(x_1)} \qquad (2)$$

（1）の関係を用いると，（2）式より

$$\Delta'=-\log\frac{\sigma(x_1)\cdot\exp(-\alpha\cdot c/n)}{\sigma(x_1)}=\frac{\alpha\cdot c}{n} \qquad (3)$$

内部摩擦の原因には hysteresis loss に由来するものと，変位速度勾配に由来するものがあると言われている[2]。

Gemant と Jackson は多くの物質の対数減衰率 Δ' は振動数のかなりの範囲にわたって一定であり，この場合の内部摩擦の主な原因は静的応力—歪み関係の非線形性に関連づけられるとしている。一方ではかなりの物質，例えば高分子化合物のようなものは変位速度勾配と結びつけられるエネルギー損失を示している。コンクリート，モルタル，セメントペーストの対数減衰率に関する既往の報告の概要は次の通りである。

i 供試体の材令が大きいほど対数減衰率 Δ' は小さくなる。
ii 供試体が湿潤状態にあるほど Δ' は大きくなる。
iii 供試体の形状寸法は Δ' にほとんど影響を与えない。
iv 供試体の品質は Δ' にほとんど影響を与えない。
v 振動数は Δ' にほとんど影響を与えない。
vi 応力波の振幅は Δ' にほとんど影響を与えない。
vii 振動力のモード（曲げ振動，ねじれ振動，縦振動）は事実上同一の Δ' を与える。
viii 供試体にクラックがあると，Δ' は大きくなる。
ix プレストレスによってクラックの発生が抑制されると Δ' は減少する。

加藤[3]は載荷履歴を受けたコンクリート供試体について，ある応力レベル以上に載荷された供試体の Δ' は急昇することを明らかにし，その理由として網状モルタルひびわれ形成をあげている。又，載荷前の対数減衰率 Δ' は圧縮強度の一次関数で表わされ圧縮強度の高いものほど対数減衰率は小さくなるとしている。山口，奥村[4]は岩石の実験で，多くの岩石では減衰定数 α は振動数に比例することを見出している。又，応力レベルの違いが減衰定数 α に影響をおよぼす傾向が見られることを指摘している。

§ 4 減衰定数の測定

4．1 実験の概要 断面 5 cm × 5 cm の 1：2 モルタル（水セメント比43％）の角柱の中央断面に半導体ゲージ KSN-6-350（G.F.＝−86）2枚を貼布し，これに鋼球によって縦衝撃を加えた（**図 2**）。モルタルの特性を**表 1**に示す。鋼球は重量 422gr，133gr，27gr の3通りを用いた。角柱の長さ l は最

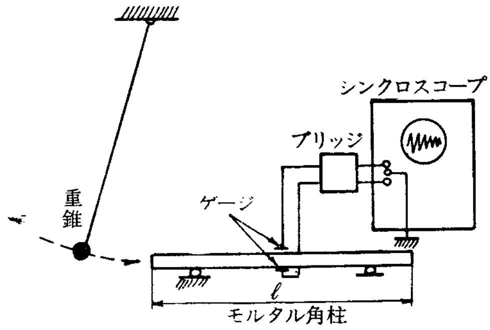

図2　衝撃実験装置

表1　モルタル供試体の特性

圧縮強度	414 kg/cm^2
引張強度	43 〃 〃
ヤング係数	2.85×10^5 〃 〃
動弾性係数	3.20×10^5 〃 〃
単位重量	$2.25\times10^{-3}kg/cm^3$

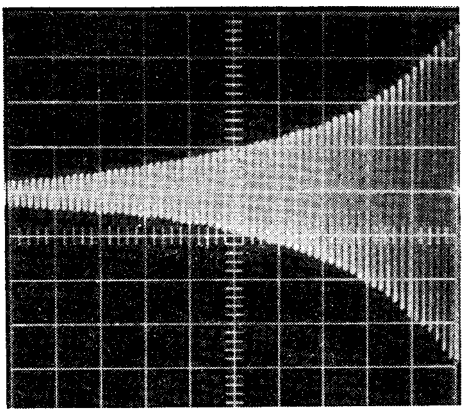

写真1　応力波形（$l=60cm$）
縦：$4.9kg/cm^2$/div
横：2msec/div

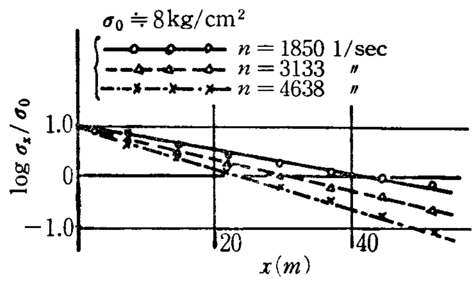

図3　$\log\frac{\sigma_x}{\sigma_0}$ と x との関係

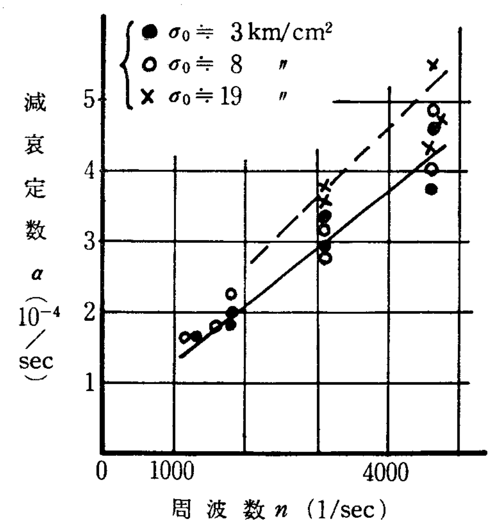

図4　減衰定数一周波数曲線

初 160cm として実験を行い，次に供試体の両端を同じ長さだけ切り取り，長さ l を 100，60，40cm として同様な測定を繰り返した。衝撃の結果，得られた応力波形の1例を**写真1**に示す。この波形から応力波の伝ぱ距離 $x(=c\cdot t)$ と $\log(\sigma_x/\sigma_0)$ との関係を求めると**図3**のようにおおよそ直線となる。この直線の傾きとして（1)′ 式で定義された減衰定数 α が得られる。かようにして得られた減衰定数 α と振動数 $n(=c/2\cdot l)$ との関係を求めると**図4**のようになる。**図4**の中で実線は $\sigma_0\fallingdotseq3kg/cm^2$ 及び $\sigma_0\fallingdotseq8kg/cm^2$ の場合をまとめたもので，点線は $\sigma_0\fallingdotseq19kg/cm^2$ の場合のものである。$\Delta'=c\cdot\alpha/n=2l\cdot\alpha$ の関係を用いると，**図4**の中の実線及び点線については次のようになっている。

$\sigma_0=3\sim8kg/cm^2$ の場合

$$\begin{cases}\alpha=6\times10^{-5}+8\times10^{-8}\times n\\ \Delta'=2.96\times10^{-2}+1.2\times^{-4}\times l \qquad 但し\ 40\leqq l\leqq160\end{cases}$$

$\sigma_0 \fallingdotseq 19kg/cm^2$ の場合

$$\begin{cases} \alpha = 5\times10^{-5}+1.02\times10^{-7}\times n \\ \Delta' = 3.89\times10^{-2}+10^{-4}\times l \end{cases} \qquad 但し\ 40\leqq l\leqq 60$$

本実験では減衰定数 α は振動数 n に比例する結果は得られなかった。その結果，対数減衰率 Δ' は供試体の長さ l と共に増加することになった。又，本実験では σ_0 が $3\sim8kg/cm^2$ の範囲にある場合には σ_0 が大きくなっても α は事実上変化しなかったが，σ_0 が $18\sim20kg/cm^2$ と大きくなると σ_0 が $3\sim8kg/cm^2$ の場合よりも α は15％程度大きくなった。これは減衰定数したがって又，対数減衰率は応力レベルによって変化することを示すものと思われる。これと関連する事柄と思われるが，$\log(\sigma_x/\sigma_0)\sim x$ のグラは厳密に言えば直線にならず，わずか下方に凹んだ直線になるが，この傾向は初期応力 σ_0 が大きい場合にかなり顕著なものとなるように思われる（**図5**）。

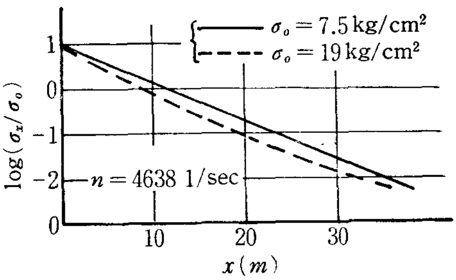

図5　初期応力 σ_0 と応力波減衰との関係

4．2　応力波の波長と応力波形との関係

本研究では打撃直後の波長 λ_0 は重さ 27gr の球の場合には $\lambda_0 \fallingdotseq 20cm$，重さ 133gr の球の場合には $\lambda_0 = 48\sim70cm$ であった。$2l>\lambda_0\geqq l$ の場合には応力波は最初からおおよそ正弦波と見做せるが（**写真2**），$\lambda_0<l$ の場合には応力波が角柱を往復する間に波長 λ は次第に長くなり，$\lambda\geqq l$ になると正弦波と見做せるようになる。$\lambda_0<l$ の場合には衝撃直後の波形は正弦波にはならない（**写真3**）。これを周波数の異なる正弦波の重なったものと見做すとき，成分正弦波の中では高周波の正弦波が多く含まれているものと考えられる。ところが高い周波数の波ほど減衰が著しいために，波長 λ が角柱の長さ l より短かい時期に減衰定数を求めると波形が長くなって正弦波と見做せるようになった以後で求める場合よりも若干大きな値を示すことが考えられる。このため，本研究では衝撃後 10～20msec の時間の間（応力波が40～80 m 伝ぱする間）で減衰定数を測定することにした。

λ_0 が比較的短かい場合には本来の応力波形に随伴して一種のうなり波形が表われ（**写真4**），減衰定数の測定が困難になる場合が多かった。今のところ，うなり波形が表われるのは $\lambda_0<l$ の場合に限定されているように思われる。このような波形の発生する原因は不明であるが，一つには供試体の内部的欠陥，又一つには波形変化に関係があるものと思われる。

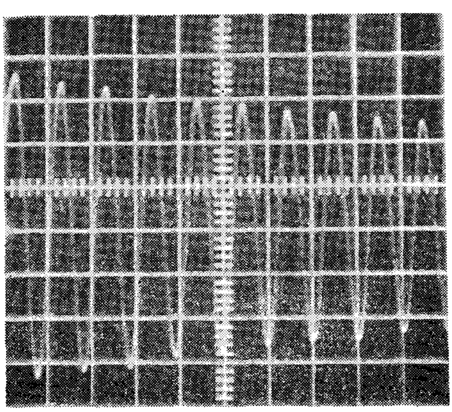

写真2　正　弦　波　形（$l=40cm$）
縦：$1.96kg/cm^2$/div
横：0.2ms/div

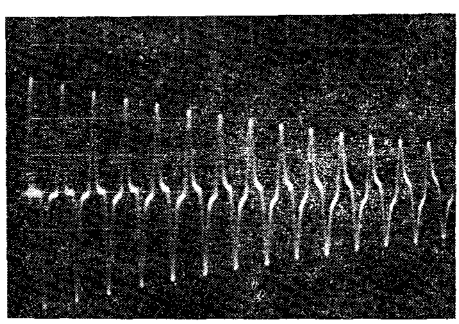

写真3　応　力　波　形（$l=160cm$）
縦：$1.96kg/cm^2$/div
横：1msec/div

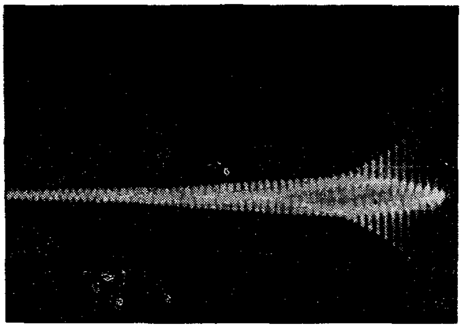

写真 4　うなりを伴なった波形（$l=160cm$）
縦：$4.9kg/cm^2$/div
横：5msec/div

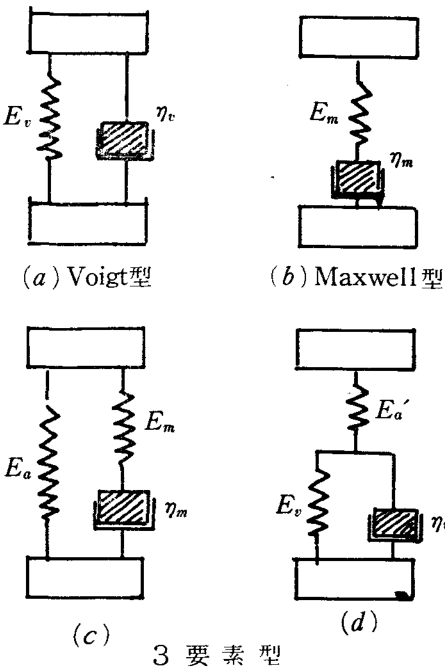

図 6　内部摩擦を表わすモデル

§ 5　内部摩擦の力学的モデル

5．1　力学的モデル　本研究では Voigt 型，Maxwell型，3要素型の3つの減衰モデル[2)]について考察する（**図 6**）。**図 6** の (c), (d) の3要素型モデルは等価であることが証明されているので本研究では3要素型としては**図 6** (c)のモデルを扱うことにする。

5．2　Voigt 型モデル　**図 6** (a)のように，ばねの弾性係数を E_v，ダッシュポットの粘性係数を η_v で表わすと，応力と歪みの関係は次のように表わされる。

$$\sigma=E_v\cdot\varepsilon+\eta_v\cdot\frac{d\varepsilon}{dt} \tag{5}$$

（5）式の両辺を x で微分する。

$$\frac{\partial\sigma}{\partial x}=E_v\cdot\frac{\partial\varepsilon}{\partial x}+\eta_v\cdot\frac{\partial}{\partial x}\left(\frac{\partial\varepsilon}{\partial t}\right) \tag{6}$$

$\frac{\partial\sigma}{\partial x}=\rho\cdot\frac{\partial^2 u}{\partial t^2}$，$\varepsilon=\frac{\partial u}{\partial x}$　を用いると（6）式から

$$\rho\frac{\partial^2 u}{\partial t^2}=E_v\cdot\frac{\partial^2 u}{\partial x^2}+\eta_v\cdot\frac{\partial}{\partial t}\left(\frac{\partial^2 u}{\partial x^2}\right) \tag{7}$$

$$u=A\cdot\exp\{i(pt-f_1\cdot x)\} \tag{8}$$

を（7）式に代入すると，

$$E_v\cdot f_1^2-\rho\cdot p^2+i\cdot f_1^2\cdot p\cdot\eta_v=0 \tag{9}$$

この方程式が解を持つためには f_1 は複素数でなければならないので，$f_1=f+i\cdot\alpha$ とおいて，これを（9）式に代入し，その実部数及び虚部数をそれぞれ等しいとおくと，

$$\begin{cases}\rho\cdot p^2=E_v\cdot(f^2-\alpha^2)-2\cdot\eta_v\cdot p\cdot f\cdot\alpha\\ 2\cdot E_v\cdot\alpha\cdot f=-\eta_v\cdot p\cdot(f^2-\alpha^2)\end{cases} \tag{10}$$

（10）式を解いて，

$$\begin{cases} f^2=\dfrac{E_v\cdot\rho\cdot p^2}{2\cdot(E_v^2+\eta_v^2\cdot p^2)}\cdot\left\{\sqrt{1+\dfrac{\eta_v^2\cdot p^2}{E_v^2}}+1\right\} \\ \alpha^2=\dfrac{E_v\cdot\rho\cdot p^2}{2\cdot(E_v^2+\eta_v^2\cdot p^2)}\cdot\left\{\sqrt{1+\dfrac{\eta_v^2\cdot p^2}{E_v^2}}-1\right\} \end{cases} \tag{11}$$

ここで $\eta_v/E_v=\tau'$ とおくと，

$$\begin{cases} f^2=\dfrac{\rho}{2\cdot E_v}\cdot\dfrac{p^2}{1+(p\cdot\tau')^2}\cdot(\sqrt{1+(p\cdot\tau')^2}+1) \\ \alpha^2=\dfrac{\rho}{2E_v}\cdot\dfrac{p^2}{1+(p\tau')^2}\cdot(\sqrt{1+(p\cdot\tau')^2}-1) \end{cases} \tag{11$'$}$$

$c=p/f$, $n=p/2\pi$ を(3)式に代入すると，

$$\Delta'=2\pi\cdot\frac{\alpha}{f} \tag{13}$$

(11)′ 式の f, α を(13)式に代入すると，

$$\Delta'=2\pi\cdot\sqrt{\frac{\sqrt{1+(p\tau')^2}-1}{\sqrt{1+(p\tau')^2}+1}} \tag{14}$$

ここで，$p\tau'\to0$ とすると $\Delta'=\pi\cdot p\cdot\tau'$ (15)

5．3 Maxwell 型モデル　**図 6** (b)のように，ばねの弾性係数を E_m，ダッシュポットの粘性係数を η_m とし，$\eta_m/E_m=\tau$ とおくと，応力と歪みの関係は，

$$\frac{d\sigma}{dt}=E_m\cdot\frac{d\varepsilon}{dt}-\frac{\sigma}{\tau} \tag{16}$$

(16)式の両辺を x で微分する。

$$\frac{\partial^2\sigma}{\partial t\cdot\partial x}=E_m\cdot\frac{\partial^2\varepsilon}{\partial t\cdot\partial x}-\frac{1}{\tau}\cdot\frac{\partial\sigma}{\partial x} \tag{17}$$

(17)式に $\dfrac{\partial\sigma}{\partial x}=\rho\cdot\dfrac{\partial^2u}{\partial t^2}$，$\varepsilon=\dfrac{\partial u}{\partial x}$ を代入すると，

$$\rho\cdot\frac{\partial^3u}{\partial t^3}-E_m\cdot\frac{\partial}{\partial t}\left(\frac{\partial^2u}{\partial x^2}\right)+\frac{\rho}{\tau}\cdot\frac{\partial^2u}{\partial t^2}=0 \tag{18}$$

前述のように $u=A\cdot\exp\{i(p\cdot t-f_1\cdot x)\}$ は f_1 が複素数でないと(18)式の解になり得ないので，$f_1=f+\alpha$ とおく。このとき，

$$u=A\cdot\exp\{\alpha\cdot x+i(p\cdot t-f\cdot x)\} \tag{19}$$

(19)式を(20)式に代入して計算すのと次の関係が得られる。

$$\begin{cases} f^2=\dfrac{\rho\cdot p^2}{2\cdot E_m}\left\{\sqrt{1+\dfrac{1}{(p\tau)^2}}+1\right\} \\ \alpha^2=\dfrac{\rho\cdot p^2}{2E_m}\left\{\sqrt{1+\dfrac{1}{(p\tau)^2}}-1\right\} \end{cases} \tag{20}$$

(20)式の f, α を(13)式に代入すると，

$$\Delta'=2\pi\cdot\sqrt{\frac{\sqrt{1+\dfrac{1}{(p\cdot\tau)^2}}-1}{\sqrt{1+\dfrac{1}{(p\tau)^2}}-1}} \tag{21}$$

$$p\tau \to \infty \text{ のとき, } \quad \Delta' = \frac{\pi}{p\tau} \tag{22}$$

5．4　3要素型モデル　**図6**(c)のように Maxwell ばね，補助ばねの弾性係数をそれぞれ E_m，E_a とし，ダッシュポットの粘性係数を η_m とし，$\eta_m/E_m=\tau$ とおくと，応力—歪みの関係は

$$\sigma+\frac{d\sigma}{dt}\cdot\tau=\frac{d\varepsilon}{dt}\cdot\tau\cdot(E_a+E_m)+E_a\cdot\varepsilon \tag{23}$$

(23)式の両辺を x で微分すると，

$$\frac{\partial\sigma}{\partial x}+\frac{\partial}{\partial t}\left(\frac{\partial\sigma}{\partial x}\right)\cdot\tau=\frac{\partial}{\partial t}\left(\frac{\partial\varepsilon}{\partial x}\right)\cdot\tau(E_a+E_m)+E_a\cdot\frac{\partial\varepsilon}{\partial x} \tag{24}$$

$\frac{\partial\sigma}{\partial x}=\rho\frac{\partial^2 u}{\partial t^2}$，$\varepsilon=\frac{\partial u}{\partial x}$　を用いると，(24)式より

$$\rho\frac{\partial^2 u}{\partial t^2}+\rho\frac{\partial^3 u}{\partial t^3}\cdot\tau=\tau\cdot(E_a+E_m)\cdot\frac{\partial^3 u}{\partial x^2\cdot\partial t}+E_a\cdot\frac{\partial^2 u}{\partial x^2} \tag{25}$$

(19)式の u を(25)式に代入して計算すると，次の関係が得られる。

$$\begin{aligned} f^2&=\frac{\rho\cdot p^2}{2}\cdot\left\{\sqrt{\frac{1+(p\cdot\tau)^2}{E_a{}^2+(p\cdot\tau)^2\cdot(E_a+E_m)^2}}+\frac{E_a+(p\cdot\tau)^2\cdot(E_a+E_m)}{E_a{}^2+(p\cdot\tau)^2\cdot(E_a+E_m)^2}\right\}\\ \alpha^2&=\frac{\rho\cdot p^2}{2}\cdot\left\{\sqrt{\frac{1+(p\cdot\tau)^2}{E_a{}^2+(p\cdot\tau)^2\cdot(E_a+E_m)^2}}-\frac{E_a+(p\cdot\tau)^2\cdot(E_a+E_m)}{E_a{}^2+(p\cdot\tau)^2\cdot(E_a+E_m)^2}\right\}\end{aligned} \tag{26}$$

(26)式の f，α を(13)式に代入すると，

$$\Delta'=2\pi\sqrt{\frac{\sqrt{\frac{1+(p\cdot\tau)^2}{1+(p\cdot\tau)^2(1+E_m/E_a)^2}}-\frac{1+(p\cdot\tau)^2\cdot(1+E_m/E_a)}{1+(p\cdot\tau)^2\cdot(1+E_m/E_a)^2}}{\sqrt{\frac{1+(p\cdot\tau)^2}{1+(p\cdot\tau)^2\cdot(1+E_m/E_a)^2}}+\frac{1+(p\cdot\tau)^2\cdot(1+E_m/E_a)}{1+(p\cdot\tau)^2\cdot(1+E_m/E_a)^2}}} \tag{27}$$

5．5　各モデルによる対数減衰率の比較

上述のように対数減衰率 Δ' は Voigt 型では $p\cdot\tau'$，Maxwell 型では $p\cdot\tau$，3要素型では $p\cdot\tau$，及び E_m/E_a のそれぞれ関数となっている。今各モデルごとに此等の変数と Δ' の関係を求めると**図7**のようになる。これを見ると，Δ' は Voigt 型では $p\cdot\tau'$ の増加と共に増加している。Maxwell 型では $p\cdot\tau$ の増加と共に減少している。一方，3要素型では $p\cdot\tau=1$ の近くで最大となり，その両側で減少している。**図7**で Voigt 型の Δ'-$p\tau'$ 曲線と Maxwell 型の Δ'-$p\cdot\tau$ で曲線とは $p\tau=1$ に関して対称になっている。§**3**で述べたように Δ' は振動数にほとんど影響されないことが言えるならば，どのモデルも適用性は良くないことになる。

モルタル角柱を用いて行った縦衝撃実験[5]（**表3の実験I**）における応力波の解析に上記の各減衰モデルを適用する。

円振動数 p は応力波の立上り時間 t_1 を用いて次のように表わせるとする。

$$p=\frac{2\pi}{T}=\frac{2\pi}{4t_1}=\frac{\pi}{2\cdot t_1} \tag{28}$$

本実験では $t_1 \doteqdot 4\times10^{-4}$sec であったので $p=3927\,{}^1/\text{sec}$ となる。対数減衰率は $\Delta'=0.05$ とし，**図7**より $p=3927$，$\Delta'=0.05$ をもたらす τ（又は τ'）を求める。この値を τ（又は τ'）の理論値と呼ぶことにする。

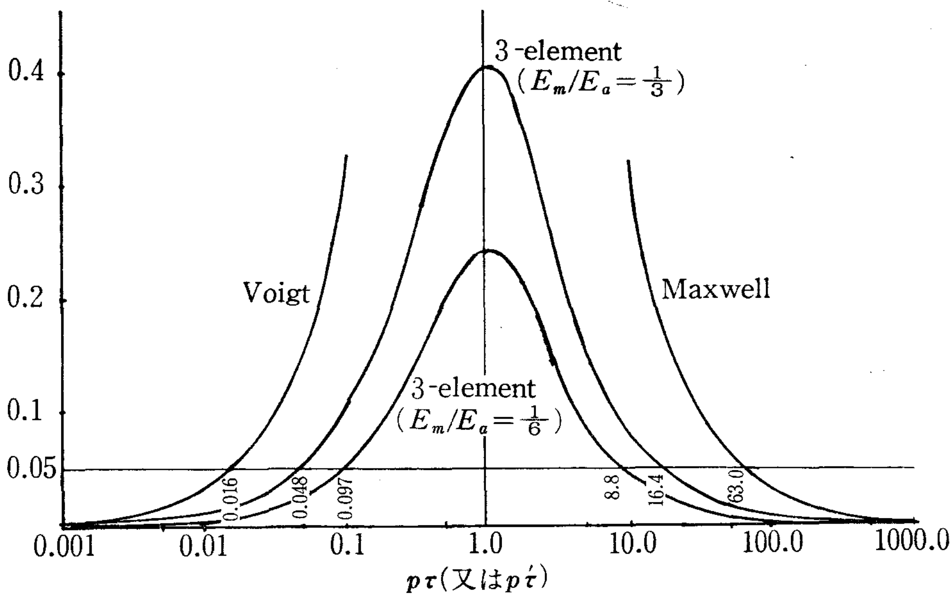

図7 $p\tau$ と Δ' との関係

一方，杭頭に実測杭頭応力波（σ_A波）を作用させ，τ（又は τ'）の値を種々に仮定してSmith 解法[6]によってゲージB位置の応力波形を計算する。その中で実測 σ_B 波形に最も近い結果をもたらすものをτ（又は τ'）の適用値と呼ぶことにする。各モデルによる理論値と適用値とを比較すると**表2**のようになる。これを見ると，理論値と適用値は一致していないが，理論値は適用値をさぐる一つの目安を与えることが出来るものと思われる。

ただし，Maxwell 型のモデルを使うと時間の経過につれて変位が大きくなる欠陥がある。又，3要素型モデルでは E_m/E_a の評価に根拠を与えることが困難である。

表2 τの理論値と実測波形適用値との比較

減衰モデル	$p\tau$ * ($\Delta'=0.05$)	τ (sec) * 理論値	τ (sec) * 適用値
Voigt 型	0.016	4.1×10^{-6}	1.0×10^{-5}
Maxwell 型	63.0	1.6×10^{-2}	1.7×10^{-3}
3要素型 $E_m/E_a=\frac{1}{6}$	0.097	2.5×10^{-5}	2.0×10^{-4}
	8.8	2.2×10^{-3}	
3要素型 $E_m/E_a=\frac{1}{3}$	0.048	1.2×10^{-5}	1.0×10^{-4}
	16.4	4.2×10^{-3}	

* Vogt 型では τ の代りに τ' とする。

§6 Voigt型モデルによる応力波形解析例

A.E.L. Smith [6] は杭の内部摩擦を考慮する必要がある場合には，Voigt 型の減衰モデルを用いることを提案している。そして遅延時間（内部減衰係数）は $\tau'=0.00001667$sec を用いることを推奨している。一方，Samson 等は $\tau'=0.000133$sec とすると，妥当な結果が得られるとしている。

ここでは**表3**に示す3種類の**実験**Ⅰ，Ⅱ，Ⅲの結果得られたゲージA及びB位置の応力 σ_A，σ_B の波形について Voigt 型の減衰モデルを用いて解析することにする。

杭コンクリートの対数減衰率を $\Delta'=0.05$ とすると，**図7**より $p\cdot\tau'=0.016$ を得る。

表3　衝　撃　実　験　の　概　要

実験	供試体	ハンマー重量(kg)	衝撃速度(cm/sec)	クッション	ゲージ* 位置(cm) A	ゲージ* 位置(cm) B
I	5×5×100cm モルタル角柱	2.418	280	かし　4 cm厚	10	70
II	ϕ12.5×381cm ヒューム管	26.58	98	ウレタン　2 cm厚	10	276
III	ϕ35×2200cm P C 杭	2200.	434	杉　10cm厚	50	980

＊供試体頭部からの距離

$$\therefore \tau' = \frac{0.016}{p} = 0.016 \times \frac{2 \cdot t_1}{\pi} \fallingdotseq t_1/100 \qquad (29)$$

実験 I，II，IIIで得られたσ_Aの波形の立上り時間t_1を(29)式に代入して得られるτ'をτ'の理論値と呼ぶことにする。一方，σ_Aの実測波形を供試体頭部に作用させて，τ'の値を種々にかえて，Smith 解法[6]でσ_Bの理論波形を求め，その中で実測波形に最も近い結果をもたらすτ'の値をτ'の適用値と呼ぶことにする。

τ'の理論値と適用値を比較すると表4のようになる。又，実験II及びIIIのσ_Bの実測波形と理論波形を比較するとそれぞれ図8，図9のようになる。これを見ると，適用値は理論値の2～4倍になっており，実際の杭打ちの場合には内部減衰係数としては$\tau'=0.0001$ sec を用いても良いものと思われる。

表4　内部減衰係数の理論値と適用値との比較

実験	供試体	応力波立上り時間 t_1(sec)	内部減衰係数 τ'(sec) 理論値	内部減衰係数 τ'(sec) 適用値
I	モルタル角柱	4×10^{-4}	4×10^{-6}	1×10^{-5}
II	ヒューム管	1×10^{-3}	1×10^{-5}	4×10^{-5}
III	P C 杭	4×10^{-3}	4×10^{-5}	1×10^{-4}

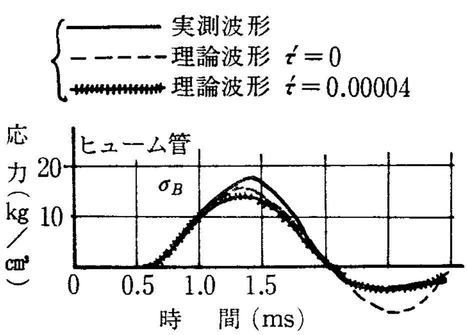

図8　実測波形と理論波形との比較（実験II）

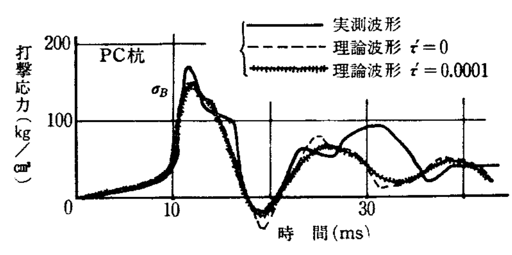

図9　実測波形と理論波形との比較（実験III）

§7　あ と が き

本研究の主要な結論は次の通りである。

i　本研究ではモルタルの減衰定数は振動数に比例しなかったが，モルタルの内部摩擦の中の相当部分は hysteresis loss によるものと思われる。この点については更に検討したい。

ii　モルタルの減衰定数，対数減衰率は応力波の振幅によって影響を受けるように思われる。

iii　Voigt 型，Maxwell 型，3要素型の3つの減衰モデルの中では，Voigt 型のものが取扱いが容易で適合性も良好であるように思われる。

iv　Voigt 型を用いる場合，遅延時間（又は内部減衰係数）τ' の適用値としては $0.02 \cdot t_1 \sim 0.04 t_1$ 程度の値を用いることが出来ると思われる。杭打ち時の応力波の解析には，$\tau'=0.0001\text{sec}$ として良いものと思われる。

終りに終始，御指導を頂いた京都大学工学部岡田清教授に厚く感謝の意を表する。

参　考　文　献

1）岡田清・久良喜代彦：コンクリート杭の打撃応力について．土木学会論文報告書，№252，1976—8
2）Kolsky, H.：Stress Waves in Solids, Dover Publications, Inc. 1963
3）加藤清志：プレーンコンクリート中のマイクロクラックと物性．土木学会論文報告集，№188，1971—4
4）山口梅太郎・奥村誠：岩石中を伝ぱする音波の減衰定数の測定．材料，21巻，228号，昭和47年9月
5）久良喜代彦：コンクリートくいの打撃引張応力に関する実験的研究．呉高専研究報告．Vol.21，№1，1976—10
6）Smith, A.E.L.：Pile Driving Analysis by the wave Equation, ASCE, 1960—8
7）岡田清・久良喜代彦・児島孝之：コンクリート管の打撃応力．土木学会第25回年次学術講演会集，1970—10
8）Samson, C.H., T.J. Hirsch and L.L. Sowery：Computer Study of Dynamic Behavior of Piling, ASCE, ST4, 1963—8

（昭和52年5月31日受付）

曲げを受けるR.C.板の降伏条件について

（土木工学科）　中　野　修　治

Yield Criterion for Reinforced Concrete Plate Subjected to Bending

Syuuzi NAKANO

The general application of the theory of plasticity to reinforced concrete plate is due to Johansen, whose stepped yield line theory is assumed that the fracture line is the limiting case of a "stepped" line in which the directions of tensile bars are at right angle to the infinitesimal steps. The others, it has been pointed out by Wood that reinforcement inclined to the fracture line may be bent across the crack in the concrete and consequently increase the ultimate moment. Kwiecinski adopted the idea that reinforcement inclined to the crack is partly kinked across it and based on his experimental observation he developed an intermediate approach called partial kinking criterion.

In this paper, we compare the stepped yield line theory with the partial kinking of reinforcemens theory, and obtain the ultimate load and the inclination of fracture line on the stepped yield line theory. The results are substantiated by data obtained from 10 experiments on reinforced concrete plates.

§1　ま　え　が　き

Wood[1]は，直交する二方向鉄筋をもつR.C.板において，一方向の塑性モーメントは，それと直角方向の鉄筋によって与えられた塑性モーメントとは無関係であると仮定した。これは "Square yield criterion" と呼ばれ，x，y方向に補強されたR.C.板において，図1に示すように，x方向の曲げモーメントM_xが$\pm M$に，y方向の曲げモーメントM_yが$\pm M$に達したとき，R.C.板は崩壊すると仮定している。ここに，Mは塑性モーメントである。この図の対角線を回転することにより，直交する他の軸nとtに変換できる。

等方性R.C.板において，鉄筋軸xとyを斜めに横切る破壊線上で，両鉄筋が降伏するとし，直交する他の軸nとtに対して（図2参照），

$$M_{pn}=M\cos^2\theta+M\sin^2\theta=M$$

同様に　$M_{pt}=M$

しかしこの変換は，全ての方向が一定のモーメント状態である点A（図1参照）に対してのみ適用される。そして，破壊線上の他の場所では，破壊線を横切るモーメントは最大塑性モーメントを生じ，$M=M_{pn}$，$M>M_{pt}$となり，破壊線を横切るM_{pn}は主モーメントとなる。

また，"Square yield criterion" から異方性R.C.板に対し，$M_x=M_{px}$，$M_y=M_{py}$とおいて，軸nとtに対し

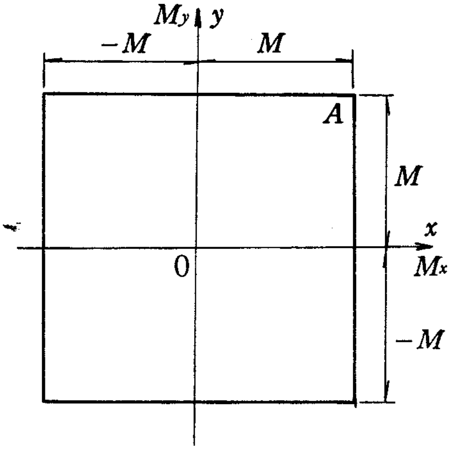

図1　Square yield criterion

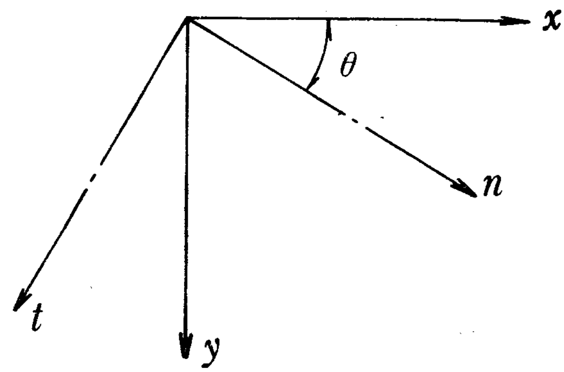

図2　直交座標軸の回転

$$M_{pn}=M_{px}\cos^2\theta+M_{py}\sin^2\theta$$

$$M_{pt}=M_{px}\sin^2\theta+M_{py}\cos^2\theta$$

これは図3に示すように，破壊線のstepに鉄筋が直交しているとする Stepped yield line theory である。

しかし，R.C.板は曲げによりねじりを生ずる。そして，x，y方向鉄筋が破壊線に沿って降伏すれば，上に述べた塑性モーメントM_{pn}を越える。そこで図4に示すように，破壊線に対して直角に引張られた鉄筋を考え，鉄筋の方向変化により，破壊線上の塑性モーメントは次のようになる。

$$M_{pn}=M_{px}\cos\theta+M_{py}\sin\theta$$

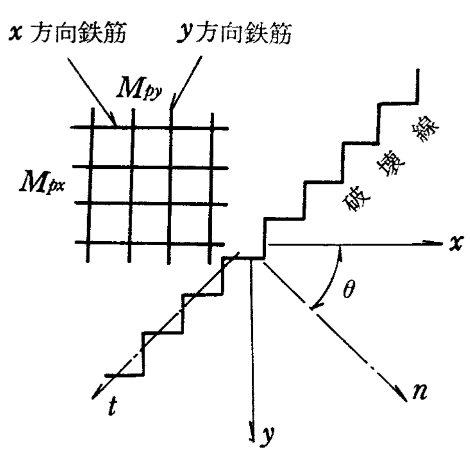

図3　Stepped yield line theory

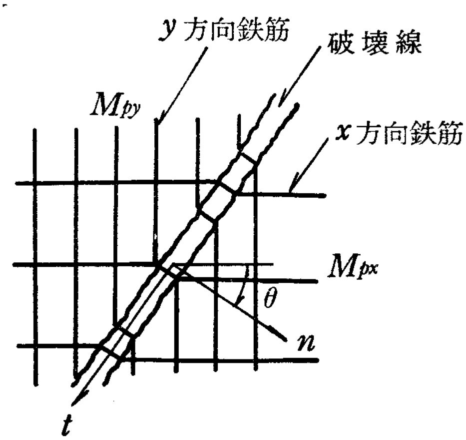

図4　Complete kinking of reinforcement theory

この理論は，Complete kinking of reinforcement theory と呼ばれる。

両理論のうち，前者は破壊線上で鉄筋はまっすぐであるとし，実験結果と異なっている。また後者は，コンクリートの圧縮による鉄筋のわずかな方向変化を過大評価している。

そこで Kwiecinski [2),3)] は，実験から得た破壊線上の鉄筋の小さな方向変化を考慮して解析を行い，Partial kinking of reinforcement theory を展開した。

本研究では，Stepped yield line theory を用い，一方向曲げ及び二方向曲げを受ける R.C. 板の終局荷重及び降伏線の傾きを求めた[4]。さらに引張り鉄筋の破壊線上の方向変化の影響を調べるために，一方向曲げを受ける等方性 R.C. 板の終局荷重を Partial kinking of reinforcement theory を用いて求め，Stepped yield line theory を用いて求めた値と比較した。

両理論の妥当性を検討するため，供試体として等方性及び異方性 R.C. 板を製作し，一方向曲げによる載荷実験を行った。

§２ 理論解析

(1) Stepped yield line theory

直交する二方向鉄筋 x，y をもつ R.C. 板要素の終局状態を，図５に示す。この要素は，載荷重による主モーメント M_1，M_2を受けている。x，y 方向の単位幅あたりの塑性モーメントを各々M_{px}，M_{py}，主モーメントの方向１と x 方向鉄筋のなす角を ϕ，方向１と破壊線の方向 t の垂線 n とのなす角を ψ として，n-t 軸系の塑性モーメント成分は次のようになる。

$$
\begin{aligned}
M_{pn} &= M_{px}\cos^2(\phi+\psi)+M_{py}\sin^2(\phi+\psi)\\
M_{pt} &= M_{px}\sin^2(\phi+\psi)+M_{py}\cos^2(\phi+\psi)\\
M_{pnt} &= (M_{px}-M_{py})\sin(\phi+\psi)\cos(\phi+\psi)
\end{aligned}
\qquad (1)
$$

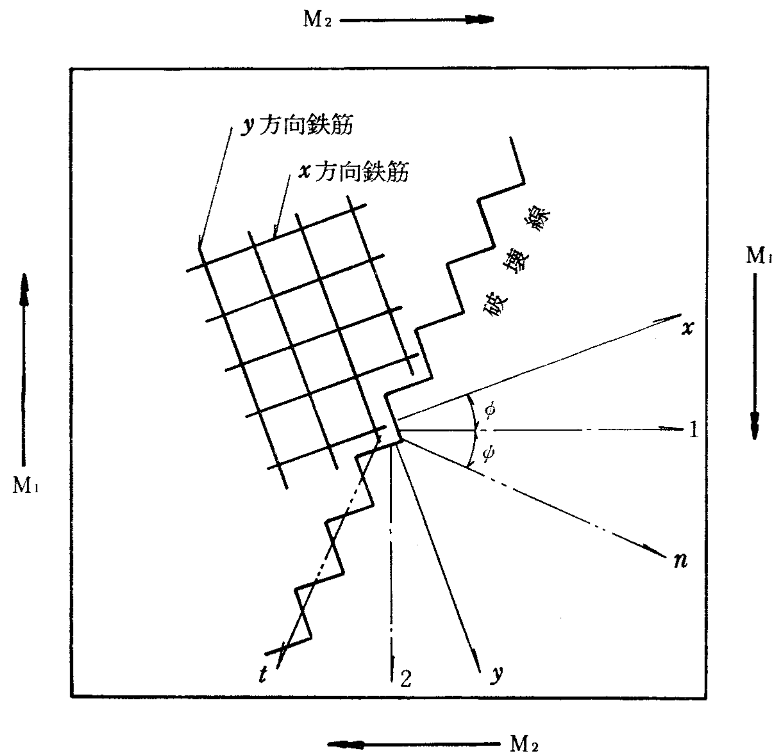

図５　Stepped yield line theory によるＲ．Ｃ．板要素

塑性モーメント M_{px}，M_{py} は，図６に示す，曲げによる終局破壊時における Hognestad のコンクリートストレスブロック[5]を用いて求められる。

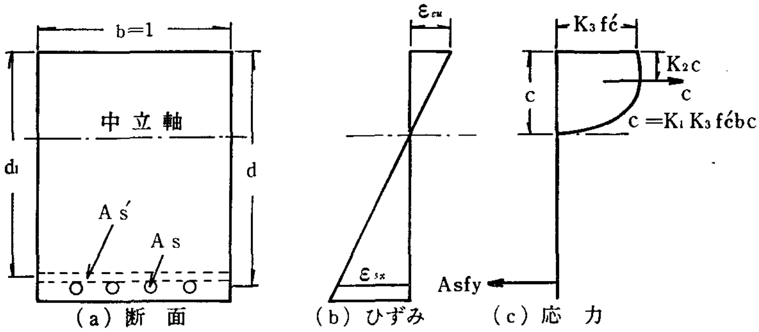

図6　Hognestad's concrete stress block

$$M_{px}=A_s f_y\left(d-\frac{K_2 A_s f_y}{K_1 K_3 f_c'}\right)$$
$$M_{py}=A_s' f_y\left(d_1-\frac{K_2 A_s' f_y}{K_1 K_3 f_c'}\right) \quad (2)$$

ここに

A_s ：単位幅あたりの，最初に置かれた x 方向鉄筋の面積（cm^2）

A_s' ：単位幅あたりの，x 方向鉄筋の上に直接直角に置かれた y 方向鉄筋の面積（cm^2）

d ：圧縮端から，最初に置かれた x 方向鉄筋の中心までの距離（cm）

d' ：圧縮端から，y 方向鉄筋の中心までの距離（cm）

f_c' ：コンクリートの圧縮強さ（kg/cm^2）

f_y ：鉄筋の降伏応力（kg/cm^2）

K_1 ：圧縮応力分布の圧縮域での平均値と最大応力度との比

$f_c'\leqq 280kg/cm^2$；$K_1=0.85$，$f_c'\geqq 280kg/cm^2$；$K_1=0.85-0.05(f_c'-280)/70$

K_2 ：合力の作用位置を表わす係数　$K_2=K_1/2$

K_3 ：圧縮応力の最大値の，コンクリートの圧縮強度 f_c' に対する比　$K_3=0.85$

又，破壊線上に働いている作用モーメント成分は，n-t 軸系を用いて次のようになる。

$$M_n=M_1\cos^2\phi+M_2\sin^2\phi$$
$$M_t=M_1\sin^2\phi+M_2\cos^2\phi \quad (3)$$
$$M_{nt}=(M_1-M_2)\sin\phi\cos\phi$$

破壊線に垂直方向の作用モーメント M_n に対する塑性モーメント M_{pn} の比は，破壊線上において最小であるという，最小抵抗の原理

$$\frac{\partial}{\partial\phi}\left(\frac{M_n}{M_{pn}}\right)=0$$

を用いて，次の式が得られる。

$$M_{pnt}\cdot M_n-M_{nt}\cdot M_{pn}=0 \quad (4)$$

降伏条件 $M_n=M_{pn}$ より，式(4)から $M_{nt}=M_{pnt}$ が求められる。したがって，これら2式に式(1)，(3)を代入して，各々次のようになる。

$$M_1\cos^2\phi+M_2\sin^2\phi=M_{px}\cos^2(\phi+\psi)+M_{py}\sin^2(\phi+\psi) \quad (5)$$

$$(M_1-M_2)\sin\phi\cos\phi=(M_{px}-M_{py})\sin(\phi+\psi)\cos(\phi+\psi) \quad (6)$$

上式は，R.C. 板が二方向曲げを受けるとき，破壊線に沿う最小抵抗の線上で，作用ねじりモーメントと塑性ねじりモーメントが等しいことを表わしている。そして，破壊線は，作用垂直モーメントが塑性垂直モーメントに等しくなる方向に生ずることを表わしている。

$\alpha=M_2/M_1$，$\beta=M_1/M_{px}$，$\mu=M_{py}/M_{px}$ とおき，式(5)，(6)を簡単化すると次のようになる。

$$M_1=M_{px}\frac{(P+\alpha Q)-\sqrt{(P+\alpha Q)^2-4\mu\alpha}}{2\alpha} \quad (7)$$

$$\tan 2\psi=\frac{(1-\mu)\sin 2\phi}{\beta(1-\alpha)-(1-\mu)\cos 2\phi} \quad (8)$$

ここに　$P=\sin^2\phi+\mu\cos^2\phi$，$Q=\cos^2\phi+\mu\sin^2\phi$

式(7)及び(8)は，等方性及び異方性 R.C. 板が，二方向曲げを受けるときの降伏条件を示している。M_{px} と M_{py} は，板断面と二方向鉄筋から求められる。式(7)は，増加している荷重による主モーメント M_1 が右辺に等しくなったとき，R.C. 板が終局状態になることを示し，そのときの破壊線の方向は，式(8)から求められる。

(a) **等方性 R.C. 板**：異方性係数 $\mu=1.0$ より，式(7)及び(8)は，各々 $M_1=M_{px}$，$\psi=0$ となる。これは，等方性 R.C. 板が二方向曲げを受けるとき，破壊線のいかなる方向においても同じ抵抗能力をもち，その方向は主モーメント軸に垂直であることを表わしている。

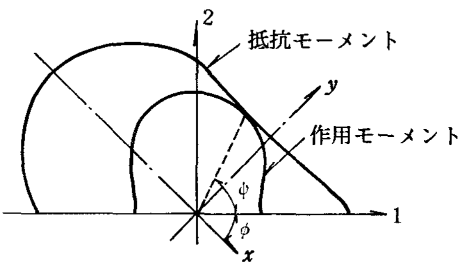

図7　二方向曲げを受ける，異方性Ｒ．Ｃ．板の降伏条件

(b) **異方性 R.C. 板**：$\mu\neq1.0$ より，図7に示すように，塑性モーメントと作用モーメント曲線の接触点は，主モーメント軸と角ϕをなす。それ故，破壊線上には，作用垂直モーメントの他に作用ねじりモーメントが働いている。

又，一方向曲げ M_1 のみを受けるとき，$M_2=0$ として，式(5)，(6)は式(9)，(10)に簡単化される。

$$M_1=\frac{\mu}{P}M_{px} \quad (9)$$

$$\tan 2\psi=\frac{(1-\mu)\sin 2\phi}{\beta-(1-\mu)\cos 2\phi} \quad (10)$$

式(9)及び(10)は，等方性及び異方性 R.C. 板が，一方向曲げを受けるときの降伏条件を示している。式(9)は，増加している荷重による主モーメント M_1 が $\mu M_{px}/P$ に等しくなったとき，終局状態になることを表わしている。そして破壊線の方向は，式(10)から求められる。

(a) **等方性 R.C. 板**：$\mu=1.0$ で $M_1=M_{px}(=M_{py})$，$\psi=0$となり，二方向曲げを受ける場合と同じである。$\psi=0$ の場合を極座標を用いて表わせば，図8となる[6]。この図において，塑性モーメントは全ての方向において等しく，破線は，終局前の作用モーメント曲線を表

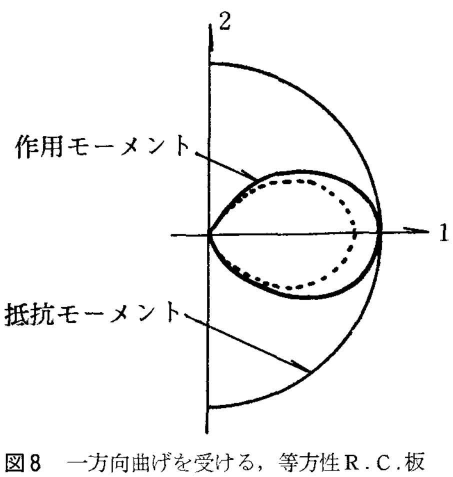

図8　一方向曲げを受ける，等方性Ｒ．Ｃ．板の降伏条件

わし，荷重の増大により $\phi=0$ で塑性モーメント曲線に接している。

（b） **異方性 R.C. 板**：図9に示すように，塑性モーメント曲線と作用モーメント曲線の接触点は，主モーメント軸と角ϕをなす。したがって，破壊線上には作用垂直モーメントの他に，作用ねじりモーメントが働いている。

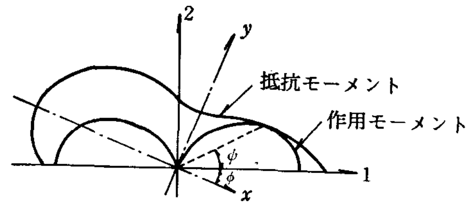

図9　一方向曲げを受ける，異方性R.C.板の降伏条件

（2） Partial kinking of reinforcement theory

等方性 R.C. 板の場合，図10において，x 方向鉄筋と破壊線のなす角を ϕ，破壊線上の x，y 方向鉄筋が破壊線の垂線となす角を各々 γ，δ とする。このとき，n-t 軸系の塑性モーメント成分は次のようになる。ここで，等方性より，$M_{px}=M_{py}=M$ とおく。

$$\begin{aligned} M_{pn} &= M(\cos\phi\cdot\cos\gamma+\sin\phi\cdot\cos\delta) \\ M_{pt} &= M(\sin\phi\cdot\sin\gamma+\cos\phi\cdot\sin\delta) \\ M_{pnt} &= M(\cos\phi\cdot\sin\gamma-\sin\phi\cdot\sin\delta) \end{aligned} \tag{11}$$

なお，$\gamma=\phi$，$\delta=\pi/2-\phi$ とおけば，等方性の場合の式(1)が得られる。

式(11)において，ϕ と γ の関係を求めるために，実験より決められる次のパラメータWを用いる。

$$W=\frac{M_{pn}}{M}\quad(\phi=\text{const}) \tag{12}$$

ここにϕは，"Square yield criterion" より 45° となる。ϕ と γ の線形関係を，次のように仮定する。

$$\sin\gamma=A(W)\sin\phi \tag{13}$$

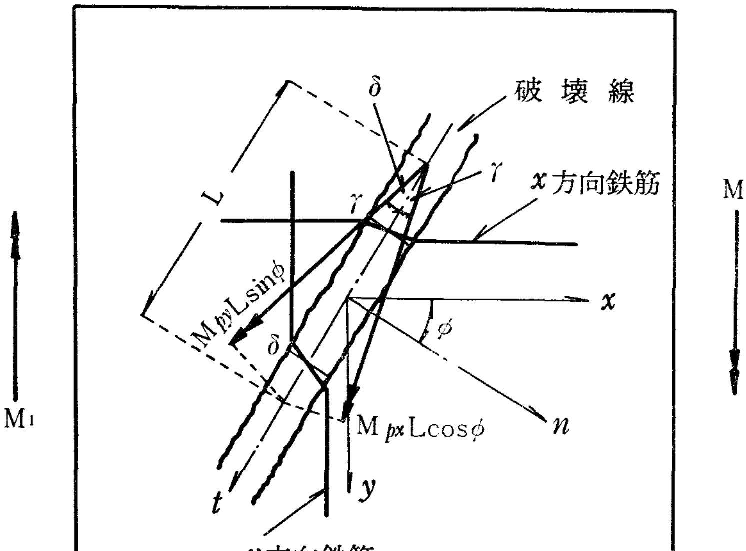

図10 Partial kinking of reinforcement theory によるR.C.板要素

ここで，対称性より $\gamma=\delta$ とおく。$\phi=45°$ より，式(11)の第1式と式(12)から

$$\cos\gamma=\frac{W}{\sqrt{2}}$$

よって式(13)から

$$A(W)=\sqrt{2-W^2}$$

したがって，最初等方性であったR.C.板の降伏条件は，次のようになる。

$$M_{pn}=M(\sqrt{1-A^2\sin^2\phi}\cdot\cos\phi+\sqrt{1-A^2\cos^2\phi}\cdot\sin\phi) \quad (14)$$

$$1\geqq A=\sqrt{2-W^2}\geqq 0 \quad (15)$$

式(15)において，$A(W)=1$ の場合，Stepped yield line theory に，$A(W)=0$ の場合，Complete kinking of reinforcement theory に相当する。

式(14)より，最初等方性であったR.C.板の破壊線上の塑性モーメント M_{pn} は，鉄筋の傾きに関係していることがわかる。つまり，等方性R.C.板は，破壊線を横切る鉄筋の小さな方向変化により，塑性域において異方性となる。

一方向曲げモーメント M_1 が働くとき，Partial kinking of reinforcement theory にもとづく降伏条件は，次のようになる。破壊線の方向は，主モーメント軸1に垂直であるから，破壊線上において $M_1=M_{pn}$ である。したがって，式(14)より，

$$M_1=M(\sqrt{1-A^2\sin^2\phi}\cdot\cos\phi+\sqrt{1-A^2\cos^2\phi}\cdot\sin\phi) \quad (16)$$

したがって，荷重の増大により，式(16)の M_1 が右辺に等しくなったとき，R.C.板は終局状態となる。

等方性R.C.板が一方向曲げを受けるときの降伏条件の3つの理論，Stepped yield line theory, Complete kinking of reinforcement theory そして Partial kinking of reinforcement theory による塑性モーメントの比較を図11に示している。この図からわかるように，Partial kinking of reinforcement theory は，他の理論値の中間値を示している。

§3 供試体及び実験方法

実験は，約370kg/cm^2 の圧縮強さをもつモルタルで作られた，10個のR.C.板を用いて行い，等方性（種類A）及び異方性（種類B）の二種類の供試体を製作

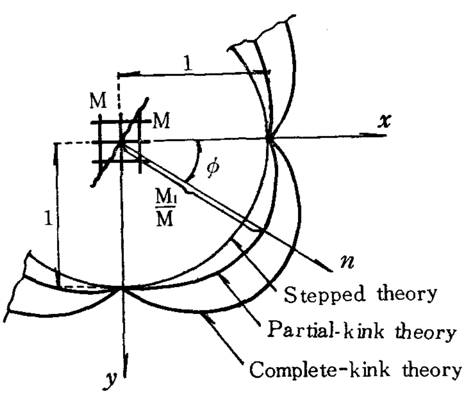

図11 等方性R.C.板の降伏条件の比較

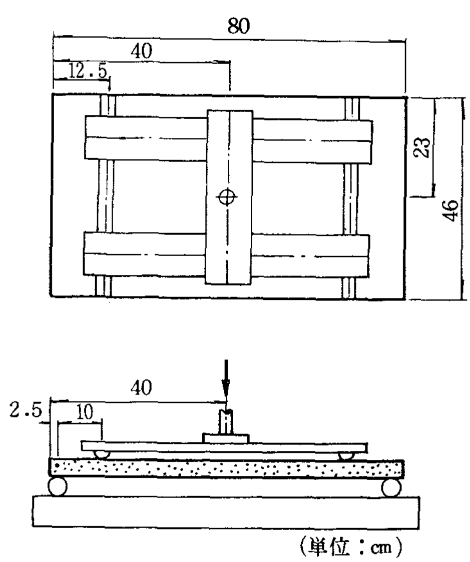

図12 載荷及び支持方法

した。その大きさは，長さ80*cm*，幅46*cm*，厚さ約4*cm*で，鉄筋として引き伸ばした番線ϕ3.2*mm*，3.9*mm*を用いた。この番線の平均降伏応力は，2480kg/cm^2であった。x方向鉄筋を下端から5*mm*に置き，y方向鉄筋は，その上に直接直角に置いた。x方向の鉄筋間隔は5.0*cm*，y方向は，種類Aは4.3*cm*，種類Bは5.5*cm*で，μ=0.55の場合は鉄筋比を変えるために，ϕ3.2*mm*の番線を用いた。

支持方法は，二辺単純他端自由とし，載荷方法は，板幅を横切る二つの等分布線荷重を各々の単純支持から12.5*cm*に，板の中心に関して対称に置いた（図12参照）。

§4　実験結果及び検討

実験後の，下面からみたR.C.板の破壊例を図13に示す。全てのR.C.板は釣合い鉄筋比以下であるので，写真1に示すように引張り破壊を起こした。

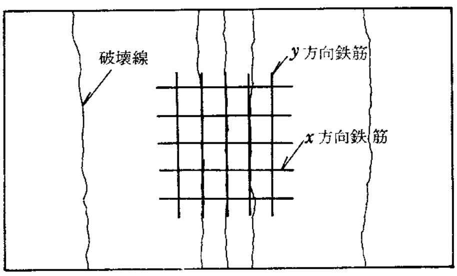

図13（1）A 1

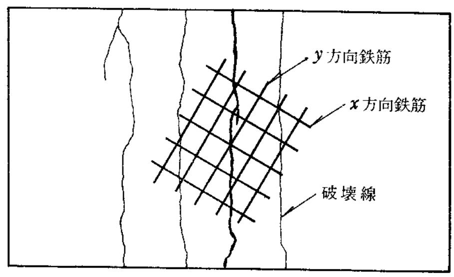

図13（2）A 2

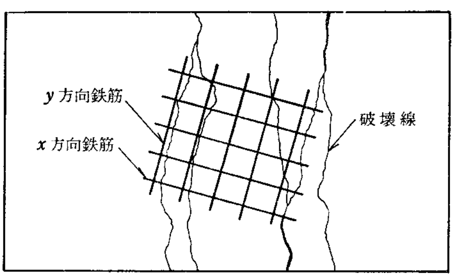

図13（3）B 1

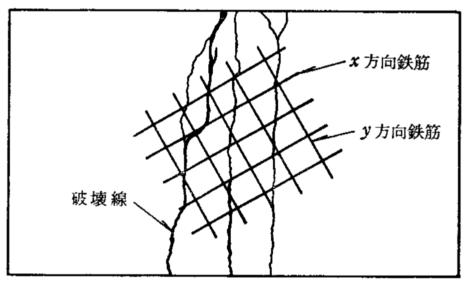

図13（4）B 4

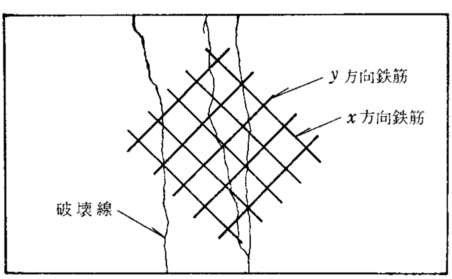

図13（5）B 7

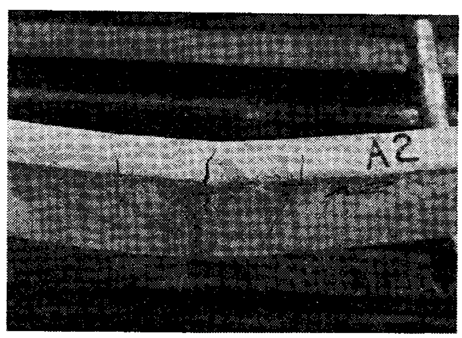

写真1　R.C.板の引張り破壊例（A 2）

理論値と実験値の結果を表1に示す。種類Aの，終局荷重及び実験値と理論値の比の欄は，上段がStepped yield line theoryにもとづく式(9)から求めた値，下段がPartial kinking of reinforcement theoryにもとづく式(16)から求めた値である。ここに，$W=1.006$であった。

等方性R.C.板において，終局荷重はPartial kinking of reinforcement theoryのほうがStepped yield line theoryを用いて求めた値よりも大きく，実験値に近い。種類A2の場合，4.4%の差があった。しかしながら，Partial kinking of reinforcement theoryによる塑性モーメントは，数々の仮定や実験によって決定されるパラメータを用いて求められており，さらに多くの実験による確認が必要であると思われる。種類Bの欄は，Stepped yield line theoryによる異方性R.C.板の結果を示している。異方性係数$\mu=0.8$の場合，終局荷重及び傾きψは，ほぼ理論値と実験値が一致しているが，$\mu=0.55$の場合，傾きψが若干相違している。

表1　理論値及び実験値の比較

種類	$\phi°$	μ	$\psi°$ 理論値	$\psi°$ 実験値	終局荷重 (kg) 理論値	終局荷重 (kg) 実験値	実験値/理論値
A1	0	1.0	0	0	1862	1930	1.037
					1862		1.037
A2	30	1.0	0	0	1651	1750	1.060
					1726		1.014
A3	45	1.0	0	0	1720	1730	1.006
					1720		1.006
B1	15	0.8	3.2	3.1	1788	2170	1.21
B2	30	0.8	5.7	4.4	1546	1600	1.03
B3	45	0.8	6.2	5.3	1439	1500	1.04
B4	−30	0.8	−5.6	−5.0	1586	1580	1.00
B5	15	0.55	11.0	7.5	1467	1620	1.10
B6	30	0.55	16.1	9.3	1410	1735	1.23
B7	45	0.55	16.2	5.5	1085	1150	1.06

種類A及び種類Bの実験結果より，破壊線上の鉄筋の小さな方向変化を無視し，引張り鉄筋は破壊線に直角で元の方向を保つとして終局荷重を求める，簡単なStepped yield line theoryを用いてよいと思われる。しかし，異方性係数μが小さいとき，Stepped yield line theoryが適用できるかどうか，検討する余地があると思われる。

終りに，終始御指導を頂いた愛媛大学工学部見沢繁光教授及び徳山工業高等専門学校重松恒美氏に謝意を表します。

参考文献

1) Wood, R.H. : Plastic and elastic design of slabs and plates, Thames and Hudson, 1961
2) Kwiecinski, M.W. : Yield criterion for initially isotropic reinforced slabs, Magazine of Concrete Research, Vol. 17, No. 51, June, pp. 97—100, 1965
3) Kwiecinski, M.W. : Some tests on the yield criterion for a reinforced concrete slab, Magazine of Concrete Research, Vol. 17, No. 52, Sep, pp. 135—138, 1965
4) Satish, C.J. and John, B.K. : Yield criterion for reinforced concrete slabs, Journal of the Structural Division, Vol. 100, No. 3, March, pp. 631—644, 1974
5) 小阪・森田：鉄筋コンクリート構造. 丸善，1975
6) Rolf, L. and Mete, A.S. : A yield criterion for reinforced concrete slabs, Journal of the American Concrete Institute, Vol. 64, No. 5, May, pp. 266—273, 1967

（昭和52年6月18日受付）

地盤の塑性変形に関する基礎的研究

―― 2 次元弾塑性解析 ――

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Fundamental study on the Plastic Deflection of Underlying soil

――2 Dimensional Elastic-Plastic Analysis――

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(Hiroshima Univ.) Hisao ABOSHI

This present paper describes results showing the ground to behave like a elastic-plastic analysis. In the former the stress is directly connected with the total strain by means of the elastic equations. In the latter there is, as we have seen, no such unique correspondence, and the stress-strain differential relations have to be integrated by following the history of the deformation form the initiation of plasticity at some point of the body. A process of plastic deformation has to be considered mathematically as a succession of small increments of strain, even where the overall distortion is so small that the change in external surfaces can be neglected.

§1 まえがき

土の特性を論じる場合，大きく分ければ，変形又は沈下の問題と破壊又は安定の問題との２種が取り上げられる。前者は圧密理論であり後者はせん断強度論をもとにした支持力論や斜面安定理論である。一方，支持力論や土圧論でも破壊や極限平衡論による応力だけでなく，その応力に達するに要した変形量についても考えなければ問題の解にはならない。このように変形と破壊の関係は重要な意味をもっている。変形は線型弾性論をもとにし，破壊は剛塑性論に立脚している。又，F.E.M. 解析において重要な役割をはたす構成方程式は，今日いろいろな方法で土の構成関係式を定めて非線型解析が行われている。その場合，Duncan 方法で代表される非線型弾性解析や，Zienkiewicz 又は山田らが示したような弾塑性応力－ヒズミ関係を用いる解析がよく適用される。これらの非線型解析を実際の地盤や土構造物に適用する場合にどちらを選ぶかは，土の力学特性の仮定や要求される解析精度に加えて，施工時，あるいは施工後の状態変化のいかんに大いに左右される。ここでは山田の弾塑性構成方程式を適用する。

さて，解析の基本的な考え方を少し述べると，線型弾性解析については既に述べたが，今回はさらに塑性領域に至った場合の地盤における変形と破壊特性を検討する。弾性領域では，応力は弾性方程式によって直接全ひずみと結びつけられているが，塑性領域では，応力と全ひずみとの間にはそのような一対一の対応はなく，応力とひずみの微分関係を物体内のある点で塑性状態が発生した瞬間から，変形の経路に従って積分する必要がある。塑性変形過程は，たとえ全体の変形が非常に小さくて外表面の変化を無視できる場合でも，数学的には相続いて生ずる微小ひずみ増分の集りと考えなければならない。

§ 2 Reuss の式と弾塑性構成方程式

2．1 せん断弾性ひずみエネルギー

微小六面体の応力，すなわち表面力，物体力のなす仕事として単位体積当りの弾性ひずみエネルギー W_e は

$$W_e=\frac{1}{2}(\sigma_x\varepsilon_x{}^e+\sigma_y\varepsilon_y{}^e+\sigma_z\varepsilon_z{}^e+2\tau_{yz}\gamma_{yz}{}^e+2\tau_{zx}\gamma_{zx}{}^e+2\tau_{xy}\gamma_{xy}{}^e) \quad \cdots\cdots(2.1)$$

で与えられる事はすでに述べた。この式は次のようにして

$$W_e=\frac{1}{2}[(\sigma_x'+\sigma)\varepsilon_x{}^e+(\sigma_y'+\sigma)\varepsilon_y{}^e+(\sigma_z'+\sigma)\varepsilon_z{}^e+2\tau_{yz}\gamma_{yz}{}^e+2\tau_{zx}\gamma_{zx}{}^e+2\tau_{xy}\gamma_{xy}{}^e]$$

$$=\frac{3}{2}\sigma\varepsilon^e+\frac{1}{2}(\sigma_x'\varepsilon_x{}^{e\prime}+\sigma_y'\varepsilon_y{}^{e\prime}+\sigma_z'\varepsilon_z{}^{e\prime}+2\tau_{yz}\gamma_{yz}{}^e+2\tau_{zx}\gamma_{zx}{}^e+2\tau_{xy}\gamma_{xy}{}^e)$$

の2つに分解する事が出来る。最後の表示式第1項は

$$W_v=\frac{3}{2}\sigma\varepsilon^e=\frac{1}{6}(\sigma_x+\sigma_y+\sigma_z)(\varepsilon_x{}^e+\varepsilon_y{}^e+\varepsilon_z{}^e) \quad \cdots\cdots(2.2)$$

となり体積の変化に費された弾性ひずみエネルギーである。W_e から W_v を差引いた残り

$$W_s=W_e-W_v=\frac{1}{2}(\sigma_x'\varepsilon_x{}^{e\prime}+\sigma_y'\varepsilon_y{}^{e\prime}+\sigma_z'\varepsilon_z{}^{e\prime}+2\tau_{yz}\gamma_{yz}{}^e+2\tau_{zx}\gamma_{zx}{}^e+2\tau_{xy}\gamma_{xy}{}^e) \quad \cdots\cdots(2.3)$$

は形状の変化に費されたエネルギーで，せん断弾性ひずみエネルギー又は形状弾性ひずみエネルギーと呼ばれるものである。ここで Hooke の法則から平均垂直ひずみ ε^e

$$\varepsilon^e=\frac{\varepsilon^e{}_x+\varepsilon_y{}^e+\varepsilon_z{}^e}{3}=\frac{(1-2\nu)(\sigma_x+\sigma_y+\sigma_z)}{3E}=\frac{(1-2\nu)\sigma}{E} \quad \cdots\cdots(2.4)$$

を差引き，統一的に

$$\frac{\varepsilon_x{}^{e\prime}}{\sigma_x'}=\frac{\varepsilon_y{}^{e\prime}}{\sigma_y'}=\frac{\varepsilon_z{}^{e\prime}}{\sigma_z'}=\frac{\gamma_{yz}{}^e}{\tau_{yz}}=\frac{\gamma_{zx}{}^e}{\tau_{zx}}=\frac{\gamma_{xy}{}^e}{\tau_{xy}}=\frac{1}{2G} \quad \cdots\cdots(2.5)$$

と表示される。(2.4)，(2.5)式を用い(2.1)，(2.2)，(2.3)式を応力成分で表わすと

$$W_e=\frac{\sigma_x{}^2+\sigma_y{}^2+\sigma_z{}^2-2\nu(\sigma_x\sigma_y+\sigma_y\sigma_z+\sigma_z\sigma_x)}{2E}+\frac{\tau_{yz}{}^2+\tau_{zx}{}^2+\tau_{xy}{}^2}{2G} \quad \cdots\cdots(2.6)$$

$$W_v=\frac{(1-2\nu)(\sigma_x+\sigma_y+\sigma_z)^2}{6E}=\frac{3(1-2\nu)\sigma^2}{2E} \quad \cdots\cdots(2.7)$$

$$W_s=\frac{\sigma_x{}'^2+\sigma_y{}'^2+\sigma_z{}'^2+2({}_y\tau_z{}^2+\tau_{zx}{}^2+\tau_{xy}{}^2)}{4G}$$

$$=\frac{(\sigma_x-\sigma_y)^2+(\sigma_y-\sigma_z)^2+(\sigma_z-\sigma_x)^2+6(\tau_{yz}{}^2+\tau_{zx}{}^2+\tau_{xy}{}^2)}{12G} \quad \cdots\cdots(2.8)$$

が得られる。

今，ここで等方性材料の降伏条件を考えると，ある応力状態における主応力，ひいてはその方向を決定する3次方程式の係数であり座標のとり方によってその値を変えないという不変的な性質を持つある量を考える。そしてその1次，2次，3次の不変量 J_1，J_2，J_3 をどの主応力 σ_1，σ_2，σ_3 に選ぶかに無関係な同じ形をとるべき関数 f は

$$f\ (J_1J_2J_3) = 0 \qquad \cdots\cdots\cdots(2.\ 9)$$

で書き表わされる。普通の大きさの静水圧又は等方応力が単独に作用するとき，考える材料の変形は弾性的で，さらにこれらを他の応力状態に重ね合せる場合も，第1近似として金属等の降伏は影響は受けないという実験的事実を用いると(2.9)式は簡単化される。すなわち(2.9)式のfは偏差応力の2次及び3次の不変量J_2'，J_3'の関数となり

$$f\ (J_2'J_3') = 0 \qquad \cdots\cdots\cdots(2.10)$$

で表わされる。J_2'，J_3'を主応力で表示すると$J_1'=\sigma_1'+\sigma_2'+\sigma_3'=0$に注意して

$$\left.\begin{aligned} J_2' &= -(\sigma_1'\sigma_2'+\sigma_2'\sigma_3'+\sigma_3'\sigma_1') = \frac{1}{2}(\sigma_1'^2+\sigma_2'^2+\sigma_3'^2) \\ &= \frac{1}{6}[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2] \\ J_3' &= \sigma_1'\sigma_2'\sigma_3' = \frac{1}{3}(\sigma_1'^3+\sigma_2'^3+\sigma_3'^3) \end{aligned}\right\} \qquad \cdots\cdots\cdots(2.11)$$

である。(2.10)式のfをJ_2'のみの関数とするものとし，せん断応力も含めると

$$6J_2'=(\sigma_x-\sigma_y)^2+(\sigma_y-\sigma_z)^2+(\sigma_z-\sigma_x)^2+6(\tau_{yz}^2+\tau_{zx}^2+\tau_{xy}^2)=6k^2=2Y^2 \qquad \cdots\cdots\cdots(2.12)$$

となる。kとYは各々せん断及び単軸引張降伏応力を表わし，(2.12)式は von Mises の降伏条件式と呼ばれている。

よって先に述べた(2.8)式は偏差応力の2次の不変量J_2'と$2GW_s=J_2'$の関係で結ばれ von Mises の降伏条件はいわゆるせん断弾性ひずみエネルギー説と一致する。

2.2 Reuss の方程式

ここで考えている等方弾塑性体の降伏条件は Mises の式に従うものとする。せん断応力成分も存在する座標系のとり方をした場合の Mises の降伏条件式は(2.12)式より

$$\{(\sigma_x-\sigma_y)^2+(\sigma_y-\sigma_z)^2+(\sigma_z-\sigma_x)^2+6\tau_{yz}^2+6\tau_{zx}^2-6\tau_{xy}^2\}=2Y^2=f_v$$

である。そこでせん断ひずみ増分に工学的定義によるせん断ひずみ増分$d\gamma_{ij}^p$を用いると

$$d\gamma_{ij}^p=h\cdot 12\tau_{ij}df=2\tau_{ij}d\lambda \qquad \cdots\cdots\cdots(2.13)$$

数学的定義によるせん断ひずみ増分$d\varepsilon_{ij}$を用いると

$$d\varepsilon_{ij}^p=h\cdot 6\tau_{ij}df=\tau_{ij}d\lambda \qquad \cdots\cdots\cdots(2.14)$$

となり Levy-Mises の応力-ひずみ関係式

$$d\varepsilon_{ij}^p=\sigma_{ij}'d\lambda \qquad \cdots\cdots\cdots(2.15)$$

が導出される。この Levy-Mises の応力-ひずみ増分関係は，変形量が大きく，弾性変形が無視できるほど小であるとき有用である。

一方，弾性ひずみε_{ij}^eについては

$$d\varepsilon_{ij}^e=d\left(\frac{\partial W}{\partial\sigma_{ij}}\right)=-\frac{\delta_{ij}}{3K}dp+d\left(\frac{\sigma_{ij}'}{2G}\right) \qquad \cdots\cdots\cdots(2.16)$$

$$p=-\frac{1}{3}(\sigma_x+\sigma_y+\sigma_z)$$ δ_{ij}：Kronecker のデルタ記号

となるから，全ひずみ増分 $d\varepsilon_{ij}$ は

$$d\varepsilon_{ij}=\sigma_{ij}'d\lambda-\frac{\delta_{ij}dp}{3K}+\frac{d\sigma_{ij}'}{2G} \quad \cdots\cdots(2.17)$$

と書かれ，この表示式を偏差ひずみ増分と体積ひずみ増分とに分けて，又降伏条件式を併記して

$$\left.\begin{aligned} &d\varepsilon_{ij}'=\sigma_{ij}'d\lambda+\frac{d\sigma_{ij}'}{2G}\\ &d\varepsilon_{ii}=\frac{(1-2\nu)d\sigma_{ij}}{E}\\ &\sigma_{ii}'\sigma_{ij}'=2k^2 \qquad k\text{：せん断降伏応力} \end{aligned}\right\} \quad \cdots\cdots(2.18)$$

のように表わしたものが Reuss の応力-ひずみ増分式である。

さて，(2.15)式より $d\varepsilon_{ij}{}^{p}=\sigma_{ij}'d\lambda$ であるから

$$\bar{\sigma}^2=\frac{3}{2}\sigma_{ij}'\sigma_{ii}'=\frac{3}{2}\sigma_{ij}'\frac{d\varepsilon_{ij}{}^{p}}{d\lambda} \quad \cdots\cdots(2.19)$$

となる。今，ここで塑性仕事について考察すると，塑性ひずみ増分は全ひずみ増分から，弾性ひずみ増分を引去った残りの量，すなわち

$$d\varepsilon_x{}^p=d\varepsilon_x-d\varepsilon_x{}^e\cdots,\ d\gamma_{yz}{}^p=d\gamma_{yz}-d\gamma_{yz}{}^e\cdots,\ d\varepsilon_{ij}{}^p=d\varepsilon_{ij}-d\varepsilon_{ij}{}^e \quad \cdots\cdots(2.20)$$

で与えられる。塑性ひずみによる体積の変化は零，すなわち塑性ひずみは非圧縮性とすると，

$$d\varepsilon_x{}^p=d\varepsilon_x-d\varepsilon_x{}^e=d\varepsilon_x'+d\varepsilon-d\varepsilon_x{}^e=d\varepsilon_x'-d\varepsilon_x{}^{e\prime} \quad \cdots\cdots(2.21)$$

ただし $d\varepsilon=1/3(d\varepsilon_x+d\varepsilon_y+d\varepsilon_z)$

$d\varepsilon_x{}^{e\prime}=d\varepsilon_x{}^e-d\varepsilon^e$, …, $d\gamma_{yz}{}^e$…は弾性偏差ひずみ増分である。

などの関係が成立することに注意して

(2.20)式は

$$\begin{aligned}&d\varepsilon_x{}^p=d\varepsilon_x'-d\varepsilon_x{}^{e\prime},\ \cdots,\ d\gamma_{yz}{}^p=d\gamma_{yz}-d\gamma_{yz}{}^{e\prime},\ \cdots,\ \text{又は}\\ &d\varepsilon_{ij}{}^p=d\varepsilon_{ij}'-d\varepsilon_{ij}{}^{e\prime}\end{aligned} \quad \cdots\cdots(2.22)$$

先の(2.5)式を微分して得られる関係を代入して

$$d\varepsilon_x{}^p=d\varepsilon_x'-\frac{d\sigma_x'}{2G},\ \cdots,\ d\gamma_{yz}{}^p=d\gamma_{yz}-\frac{d\tau_{yz}}{2G},\ \cdots,\ \text{又は}$$

$$d\varepsilon_{ij}{}^p=d\varepsilon_{ij}'-\frac{d\sigma_{ij}'}{2G} \quad \cdots\cdots(2.23)$$

と書き表わされる。$d\varepsilon_{ij}'$ は全偏差ひずみ増分をあらわし，全ひずみ増分 $d\varepsilon_{ij}$ から

$$d\varepsilon=d\varepsilon^e=\frac{(1-2\nu)d\sigma}{E},\ \text{ただし}\ d\sigma=\frac{d(\sigma_x+\sigma_y+\sigma_z)}{3} \quad \cdots\cdots(2.24)$$

を差引いた量と定義される。塑性仕事増分 dW_p は，全仕事増分 dW から回復可能な弾性ひずみエネルギー増分 dW_e を引去った形，

$$\begin{aligned}dW_p=dW-dW_e=&\sigma_xd\varepsilon_x{}^p+\sigma_yd\varepsilon_y{}^p+\sigma_zd\varepsilon_z{}^p+2\tau_{yz}d\gamma_{yz}{}^p\\ &+2\tau_{zx}d\gamma_{zx}{}^p+2\tau_{xy}d\gamma_{xy}{}^p\end{aligned} \quad \cdots\cdots(2.25)$$

と定義されるが，塑性ひずみの非圧縮性の条件 $d\varepsilon_x{}^p+d\varepsilon_y{}^p+d\varepsilon_z{}^p=0$ を用い又 $\sigma_x'=\sigma_x-\sigma$, …, τ_{yz}…を偏差応力とすると(2.25)式は

$$\begin{aligned}dW_p&=\sigma_x'd\varepsilon_x{}^p+\sigma_y'd\varepsilon_y{}^p+\sigma_z'd\varepsilon_z{}^p+2\tau_{yz}d\gamma_{yz}{}^p+2\tau_{zx}d\gamma_{zx}{}^p+2\tau_{xy}d\gamma_{xy}{}^p\\ &=\sigma_{ij}'d\varepsilon_{ij}{}^p\end{aligned} \quad \cdots\cdots(2.26)$$

となる。この式の最後の表示式 $\sigma_{ij}'d\varepsilon_{ij}^{p}$ は添字記号 i, j の総和規約によるものである。
先の(2.19)式は次のように

$$dW_p=\sigma_{ij}'d\varepsilon_{ij}^{p}=\bar{\sigma}d\varepsilon_p=\frac{2}{3}\bar{\sigma}^2 d\lambda \qquad \cdots\cdots(2.27)$$

となり，塑性仕事増分を意味するものであることがわかる。(2.27)式から，$d\lambda=3d\bar{\varepsilon}_p/2\bar{\sigma}$ であるから，(2.17)式は

$$d\varepsilon_{ij}=\frac{3\sigma_{ij}'d\varepsilon_p}{2\bar{\sigma}}-\frac{\delta_{ij}dp}{3K}+\frac{d\sigma_{ij}'}{2G} \qquad \cdots\cdots(2.28)$$

と書きなおされ，Prandtl-Reuss 式を得る。この式を応力増分 $d\sigma_{ij}$ に関して解いた形は弾塑性問題に F.E.M. を適用する場合に必要である。この逆変換はひずみ増分と応力増分，

$$\{d\varepsilon_{ij}\}=\begin{Bmatrix} d\varepsilon_{xx} \\ d\varepsilon_{yy} \\ d\varepsilon_{zz} \\ d\gamma_{yz} \\ d\gamma_{xz} \\ d\gamma_{xy} \end{Bmatrix}, \quad \{d\sigma_{ij}\}=\begin{Bmatrix} d\sigma_{x} \\ d\sigma_{y} \\ d\sigma_{z} \\ d\tau_{yz} \\ d\tau_{xz} \\ d\tau_{xy} \end{Bmatrix}$$

との間が $\{d\sigma_{ij}\}=[D^p]\{d\varepsilon_{ij}\}$ で関係づけられるような $[D^p]$ を求めることになる。
ベクトル $\{d\sigma_i\}$ の成分 $d\sigma_i$ は

$$d\sigma_i=\frac{\partial\sigma_i}{\partial\varepsilon_i}d\varepsilon_j \qquad \cdots\cdots(2.29)$$

と表示することができる。そして $\dfrac{\partial\sigma_i}{\partial\varepsilon_i}$ が $[D^p]$ の ij 成分となる。

2．3　弾性領域における剛性マトリックス

弾塑性問題における弾性域での Hooke の法則は，

$$\varepsilon_{ij}=\frac{\sigma_{ij}'}{2G}+\frac{\delta_{ij}(1-2\nu)\sigma_{ij}}{3E} \qquad \cdots\cdots(2.30)$$

で与えられる。E と G は縦及び横弾性係数，ν はポアソン比，$\sigma_{ij}=\sigma_x+\sigma_y+\sigma_z$，$\sigma_{ij}'$ は偏差応力，δ_{ij} は Kronecker のデルタ記号を表わす (2.30)式を σ_{ij} について解き，その結果をマトリックス表示すれば

$$\boldsymbol{\sigma}=2G\,\boldsymbol{D}^e\boldsymbol{\varepsilon}=\frac{E}{1+\nu}[\boldsymbol{D}^e]\boldsymbol{\varepsilon} \qquad \cdots\cdots(2.31)$$

ただし $[\boldsymbol{D}^e]$ は次のようになる。

$$[\boldsymbol{D}^e]=\begin{bmatrix} \frac{1-\nu}{1-2\nu} & \frac{\nu}{1-2\nu} & \frac{\nu}{1-2\nu} & 0 & 0 & 0 \\ \frac{\nu}{1-2\nu} & \frac{1-\nu}{1-2\nu} & \frac{\nu}{1-2\nu} & 0 & 0 & 0 \\ \frac{\nu}{1-2\nu} & \frac{\nu}{1-2\nu} & \frac{1-\nu}{1-2\nu} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{2} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{2} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{2} \end{bmatrix} \qquad \cdots\cdots(2.32)$$

ここで $\boldsymbol{\sigma}$ と $\boldsymbol{\varepsilon}$ は σ_{ij} と ε_{ij} を成分とする列マトリックスをあらわす，(2.31)，(2.32)式で $\boldsymbol{\varepsilon}$ のせん断成分 (ε_{ij}, $i \neq j$) は工学の定義（テンソル成分の2倍）に従つている。

応力が σ_x, σ_y, σ_z のみで，その他は，平面ひずみ問題では(2.31)式と(2.32)式より $\varepsilon_z=0$ とおくと次の式が得られる。

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} = [\boldsymbol{D}^e] \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ r_{xy} \end{Bmatrix} \qquad \cdots\cdots\cdots\cdots\cdots(2.33)$$

ただし $[\boldsymbol{D}^e]$ は

$$[\boldsymbol{D}^e] = 2G \begin{pmatrix} \dfrac{1-\nu}{1-2\nu} & \dfrac{\nu}{1-2\nu} & 0 \\ \dfrac{\nu}{1-2\nu} & \dfrac{1-\nu}{1-2\nu} & 0 \\ 0 & 0 & \dfrac{1}{2} \end{pmatrix} \qquad \cdots\cdots\cdots\cdots\cdots(3.34)$$

となり，弾性領域における平面ひずみ場の剛性マトリックスを得る。

2.4 塑性領域における剛性マトリックス

降伏条件は先の Mises の条件に従い，応力-ひずみ関係式は Reuss の式で与えられるものとすると，Reuss の式でひずみ増分 $d\varepsilon_{ij}$ の偏差成分 $d\varepsilon_{ij}'$ は

$$d\varepsilon_{ij}'=\sigma_{ij}'d\lambda+\frac{d\sigma_{ij}'}{2G}, \quad d\lambda=\frac{3}{2}\ \frac{d\bar{\varepsilon}^p}{\bar{\sigma}}=\frac{3}{2}\ \frac{d\bar{\sigma}}{\bar{\sigma}H'} \qquad \cdots\cdots\cdots\cdots\cdots(2.35)$$

σ_{ij}' 偏差応力，$\bar{\sigma}$ と $d\bar{\varepsilon}^p$ はそれぞれ相当応力，相当塑性ひずみ増分を表わす。又 $H'=\dfrac{d\bar{\sigma}}{d\bar{\varepsilon}^p}$ で表らわす H' は加工硬化率と呼ばれ，塑性域における応力-ひずみ増分の形を示すものである。

相当応力，相当塑性ひずみ増分は次のように表わす。

$$\bar{\sigma}=\sqrt{\frac{3}{2}\sigma_{ij}'\sigma_{ij}'}\ , \quad d\bar{\varepsilon}^p=\sqrt{\frac{2}{3}d\bar{\varepsilon}_{ij}{}^p d\varepsilon_{ij}{}^p} \qquad \cdots\cdots\cdots\cdots\cdots(2.36)$$

上式を書きえて

$$\bar{\sigma}^2=\frac{3}{2}(\sigma_x'^2+\sigma_y'^2+\sigma_z'^2+2\tau_{xy}^2+2\tau_{yz}^2+2\tau_{zx}^2) \qquad \cdots\cdots\cdots\cdots\cdots(2.37)$$

とし，(2.27)式を微分すると

$$\bar{\sigma}d\bar{\sigma}=\frac{3}{2}(\sigma_x'd\sigma_x'+\sigma_y'd\sigma_y'+\sigma_z'd\sigma_z'+2\tau_{xy}d\tau_{xy}+2\tau_{yz}d\tau_{yz}+2\tau_{zx}d\tau_{zx}) \qquad \cdots\cdots\cdots\cdots\cdots(2.38)$$

となる。これを(2.35)式の第2式に代入し $d\bar{\sigma}$ を消去すると，

$$d\lambda=\frac{9}{4}\ \frac{1}{\bar{\sigma}^2 H'}(\sigma_x'd\sigma_x'+\sigma_y'd\sigma_y'+\sigma_z'd\sigma_z'+2\tau_{xy}d\tau_{xy}+2\tau_{yz}d\tau_{yz}+2\tau_{zx}d\tau_{zx}) \qquad \cdots\cdots\cdots\cdots\cdots(2.39)$$

上の式に次の関係を用いて書きかえると

$$d\sigma_x'=d\sigma_x-d\sigma, \quad d\sigma_y'=d\sigma_y-d\sigma, \quad d\sigma_z'=d\sigma_z-d\upsilon$$

$$\sigma_x'+\sigma_y'+\sigma_z'=0, \quad d\sigma=\frac{1}{3}d(\sigma_x+\sigma_y+\sigma_z)$$

$$d\lambda=\frac{9}{4}\frac{1}{\bar{\sigma}^2 H'}(\sigma_x' d\sigma_x+\sigma_y' d\sigma_y+\sigma_z' d\sigma_z+2\tau_{xy}d\tau_{xy}+2\tau_{yz}d\tau_{yz}+2\tau_{zx}d\tau_{zx}) \qquad \cdots\cdots(2.40)$$

を得る。ここで(2.35)式の第1式を具体的な形に書きなおすと

$$\left.\begin{aligned}
d\varepsilon_x&=\sigma_x' d\lambda+d(\sigma_x-\nu\sigma_y-\nu\sigma_z)/E\\
d\varepsilon_y&=\sigma_y' d\lambda+d(\sigma_y-\nu\sigma_z-\nu\sigma_x)/E\\
d\varepsilon_z&=\sigma_z' d\lambda+d(\sigma_z-\nu\sigma_x-\nu\sigma_y)/E\\
d\gamma_{xy}&=2\tau_{xy}d\lambda+\frac{d\tau_{xy}}{G}\\
d\gamma_{yz}&=2\tau_{yz}d\lambda+\frac{d\tau_{yz}}{G}\\
d\gamma_{zx}&=2\tau_{zx}d\lambda+\frac{d\tau_{zx}}{G}
\end{aligned}\right\} \qquad \cdots\cdots(2.41)$$

となる。(2.40)式を(2.41)式に代入し，簡単化するために，$\tau_{yz}=\tau_{zx}=0$ の場合の問題を考えると，

$$\left.\begin{aligned}
d\varepsilon_x&=\frac{9\sigma_x'}{4\bar{\sigma}^2 H'}(\sigma_x' d\sigma_x+\sigma_y' d\sigma_y+\sigma_z' d\sigma_z+2\tau_{xy}d\tau_{xy})+\frac{d(\sigma_x-\nu\sigma_y-\nu\sigma_z)}{E}\\
&=\left(\frac{9\sigma_x'^2}{4\bar{\sigma}^2 H'}+\frac{1}{E}\right)d\sigma_x+\left(\frac{9\sigma_x'\sigma_y'}{4\bar{\sigma}^2 H'}-\frac{\nu}{E}\right)d\sigma_y+\left(\frac{9\sigma_x'\sigma_z'}{4\bar{\sigma}^2 H'}-\frac{\nu}{E}\right)d\sigma_z+\left(\frac{9\sigma_x'\tau_{xy}}{2\bar{\sigma}^2 H'}\right)d\tau_{xy}\\
d\varepsilon_y&=\left(\frac{9\sigma_x'\sigma_y'}{4\bar{\sigma}^2 H'}-\frac{\nu}{E}\right)d\sigma_x+\left(\frac{9\sigma_y'^2}{4\bar{\sigma}^2 H'}+\frac{1}{E}\right)d\sigma_y+\left(\frac{9\sigma_y'\sigma_z'}{4\bar{\sigma}^2 H'}-\frac{\nu}{E}\right)d\sigma_z+\left(\frac{9\sigma_y'\tau_{xy}}{2\bar{\sigma}^2 H'}\right)d\tau_{xy}\\
d\varepsilon_z&=\left(\frac{9\sigma_x'\sigma_z'}{4\bar{\sigma}^2 H'}-\frac{\nu}{E}\right)d\sigma_x+\left(\frac{9\sigma_y'\sigma_z'}{4\bar{\sigma}^2 H'}-\frac{\nu}{E}\right)d\sigma_y+\left(\frac{9\sigma_z'^2}{4\bar{\sigma}^2 H'}+\frac{1}{E}\right)d\sigma_z+\left(\frac{9\sigma_z'\tau_{xy}}{2\bar{\sigma}^2 H'}\right)d\tau_{xy}\\
d\gamma_{xy}&=\left(\frac{9\sigma_x'\tau_{xy}}{2\bar{\sigma}^2 H'}\right)d\sigma_x+\left(\frac{9\sigma_y'\tau_{xy}}{2\bar{\sigma}^2 H'}\right)d\sigma_y+\left(\frac{9\sigma_z'\tau_{xy}}{2\bar{\sigma}^2 H'}\right)d\sigma_z+\left(\frac{9\tau_{xy}^2}{2\bar{\sigma}^2 H'}+\frac{1}{G}\right)d\tau_{xy}
\end{aligned}\right\} \qquad \cdots\cdots(2.42)$$

となる。

平面ひずみ問題における剛性マトリックスを得るために，(2.42)式の $d\varepsilon_z=0$ とおき，$d\sigma_x$, $d\sigma_y$, $d\tau_{xy}$ について解けば，所要の応力-ひずみ剛性マトリックスがみられる。逆変換を行った結果をマトリックスの形式で表わすと，

$$\begin{Bmatrix} d\sigma_x \\ d\sigma_y \\ d\tau_{xy} \end{Bmatrix}=2G\,[\boldsymbol{D}^p]\begin{Bmatrix} d\varepsilon_x \\ d\varepsilon_y \\ d\gamma_{xy} \end{Bmatrix} \qquad \cdots\cdots(2.43)$$

ここで応力-ひずみ剛性マトリックス $[\boldsymbol{D}^p]$ は

$$[\boldsymbol{D}^p]=\begin{bmatrix}
\frac{1-\nu}{1-2\nu}-\frac{\sigma_x'^2}{S} & & SYM \\
\frac{\nu}{1-2\nu}-\frac{\sigma_x'\sigma_y'}{S} & \frac{1-\nu}{1-2\nu}-\frac{\sigma_y'^2}{S} & \\
-\frac{\sigma_x'\tau_{xy}}{S} & -\frac{\sigma_y'\tau_{xy}}{S} & \frac{1}{2}-\frac{\tau_{xy}^2}{S}
\end{bmatrix} \qquad \cdots\cdots(2.44)$$

ただし　$S=\frac{2}{3}\bar{\sigma}^2\left(1+\frac{H'}{3G}\right)$

以上で弾塑性剛性マトリックス，いわゆる構成方程式の導出を述べて来たが，弾性の問題がマトリックス有限要素法で解かれているならば，塑性状態になった要素の応力-ひずみマトリックスを $[\boldsymbol{D}^e]$ から $[\boldsymbol{D}^p]$ におきかえるだけで，ほとんど同じ計算機プログラムを用いて，弾塑性問題の解析を行う事ができる。

§3　解　析　例

今までに述べた理論展開に従って，軟弱地盤上における盛土施工などによる地盤内の変形解析を例に挙げる。y軸を深さ方向に，x軸を水平方向にとり，y軸を10.0cm，x軸を40.0cmとし，境界条件は次のように行う。両側面はy軸方向自由，x軸方向拘束とした。又，底面はy軸方向拘束節点に，x軸方向自由節点と仮定した。要素数＝213，節点数＝130，弾性係数$E=12.0kg/cm^2$，ポアソン比$\nu=0.35$とした。Eは室内三軸圧縮試験から得た応力-ひずみ曲線より取ったものである。荷重条件は主荷重と押え荷重で主荷重は降伏要素判定する場合に用いられるr_{min}で現在の荷重を換算しながら荷重を増加させ繰り返し演算を行うべく性質の荷重である。又押え荷重は，主荷重両側の地表面の盛り上がりを押えて地中の応力の緩和と変形量を少なくする事を目的としたものである。計算の結果としてσ_x，σ_y，τ_{xy}の各応力分布図，ε_x，ε_y，γ_{xy}の各ひずみ分布図，U-V 方向の変位図，又塑性域判定も図示する事が出来る。

§4　結果と考察

まず，一般の載荷試験より，荷重と沈下量曲線を図1のようにおいて塑性域への経路を垂直応力分布から順次述べていくと，図2は沈下曲線(B)点にあたり主荷重は$0.456kg/cm^2$で，押え載荷量は$0.2kg/cm^2$である。主荷重直下で大きな応力を示し，又鉛直方向にのびていることがわかる。図3は(C)点における垂直応力 σ_y の分布図である。主荷重下の応力値は大きな変化はないが，等応力線がほとんど鉛直方向に立ってきているのが特徴である。$0.2kg/cm^2$の荷重下の応力分布が先の図と比較し下方にのびている。次に図4は(B)点におけるせん断応力τ_{xy}であるが，この分布図では主荷重と押え荷重の間に大きな応力集中を呈している。又そこから底辺に向い応力線が広がっている。$0.2kg/cm^2$ の押え荷重下では応力値も緩和され，押え荷重の影響がみられる。図5はτ_{xy}の主荷重が(C)点に位置するもので，2種の荷重間の応力集中は見られるが，後方に広がりを見せている。又，応力値の大きな分布域が下方にありその範

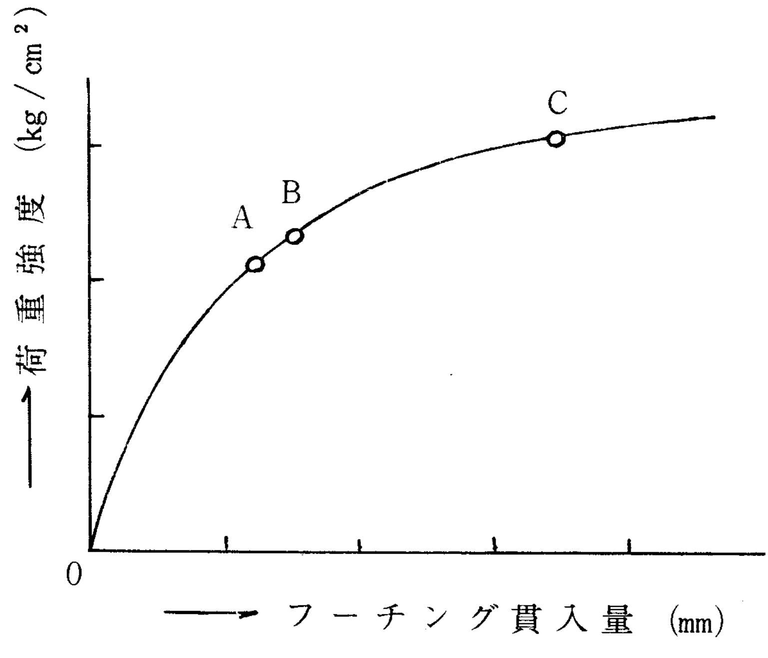

図1　載荷荷重と表面沈下量（計算値）

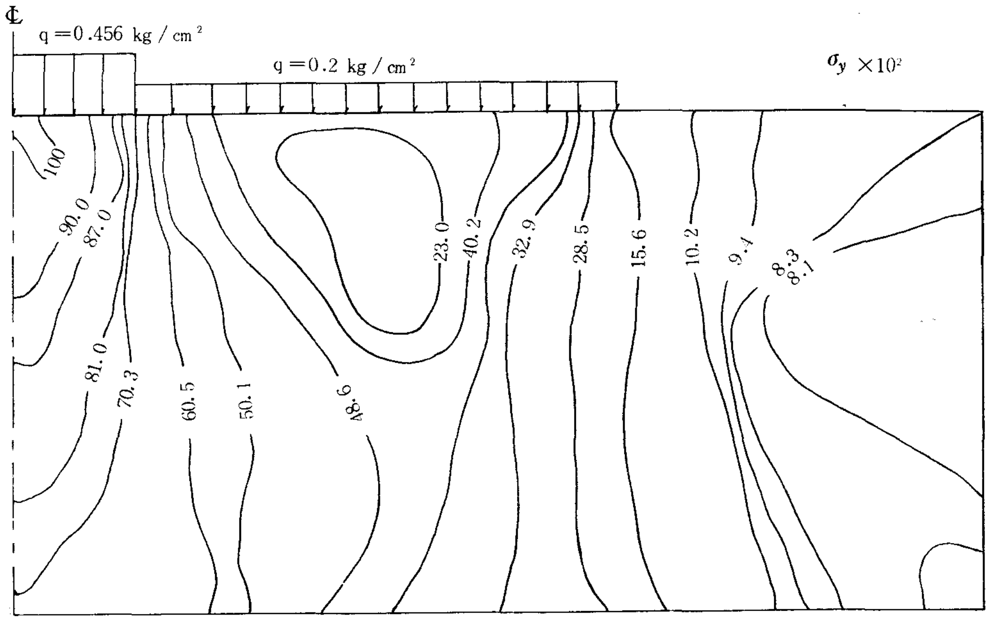

図2 (B) 点 の σ_y 分 布

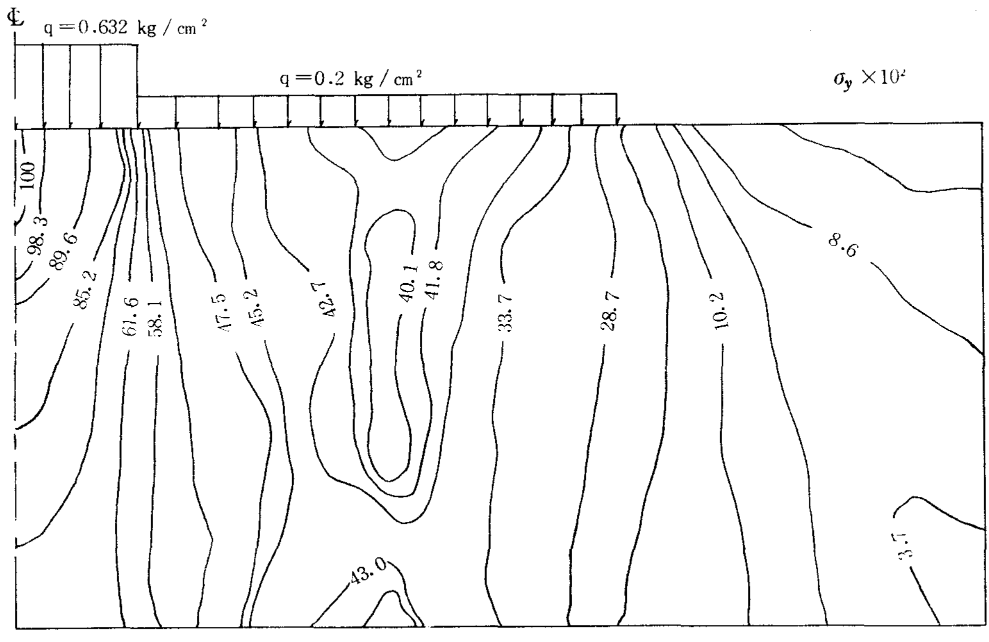

図3 (C) 点 の σ_y 分 布

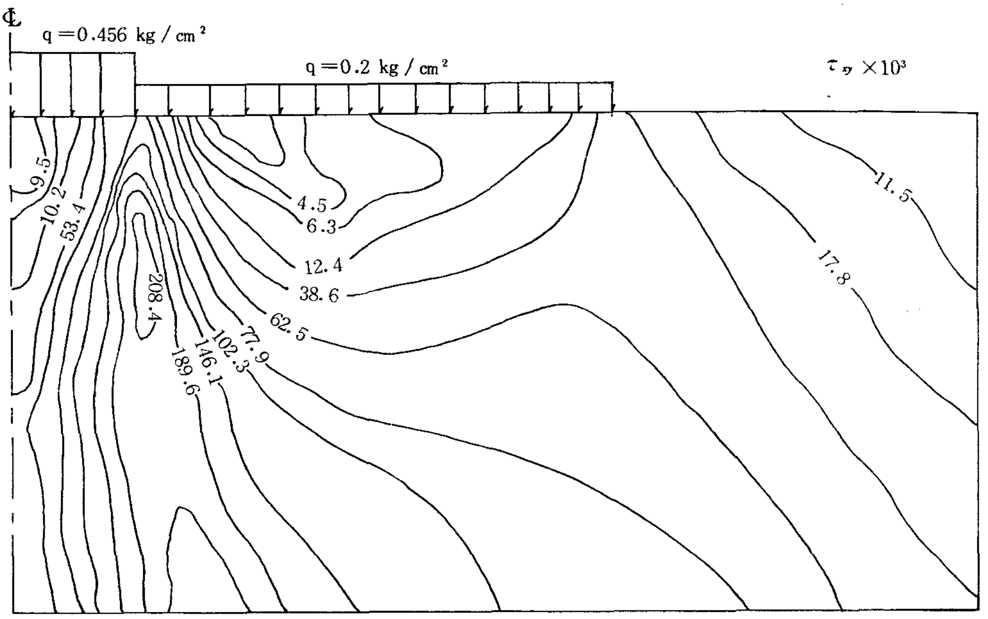

図4 (B) 点 の τ_{xy} 分 布

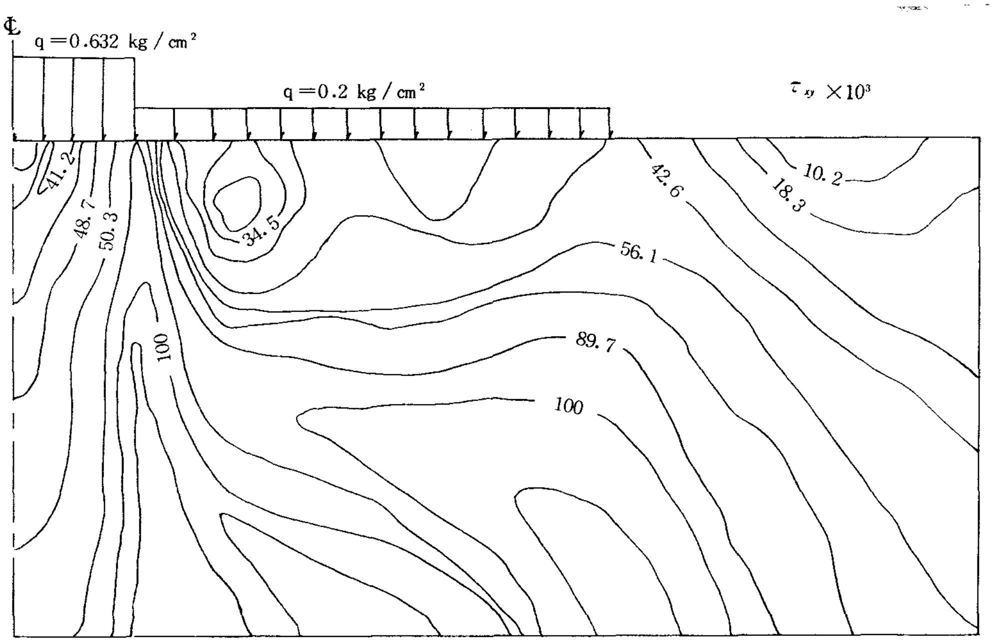

図5 (C) 点 の τ_{xy} 分 布

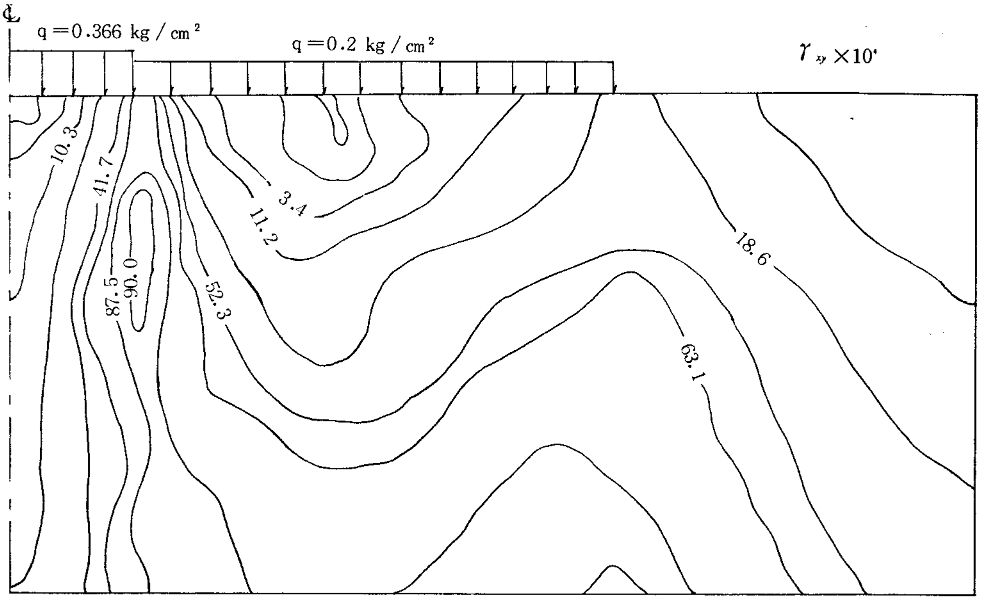

図6 (A) 点 の γ_{xy} 分 布

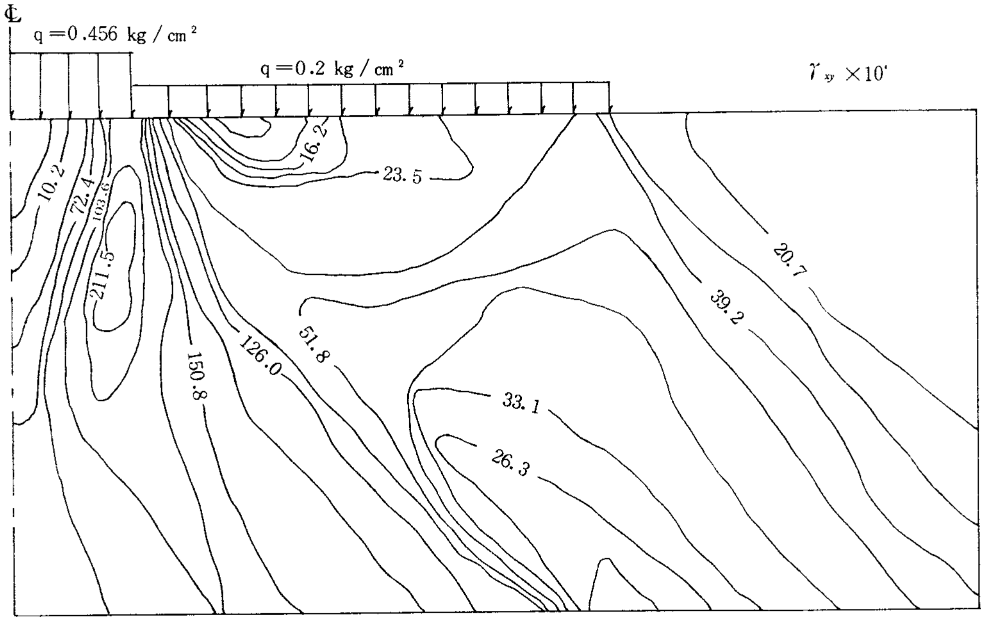

図7 (B) 点 の γ_{xy} 分 布

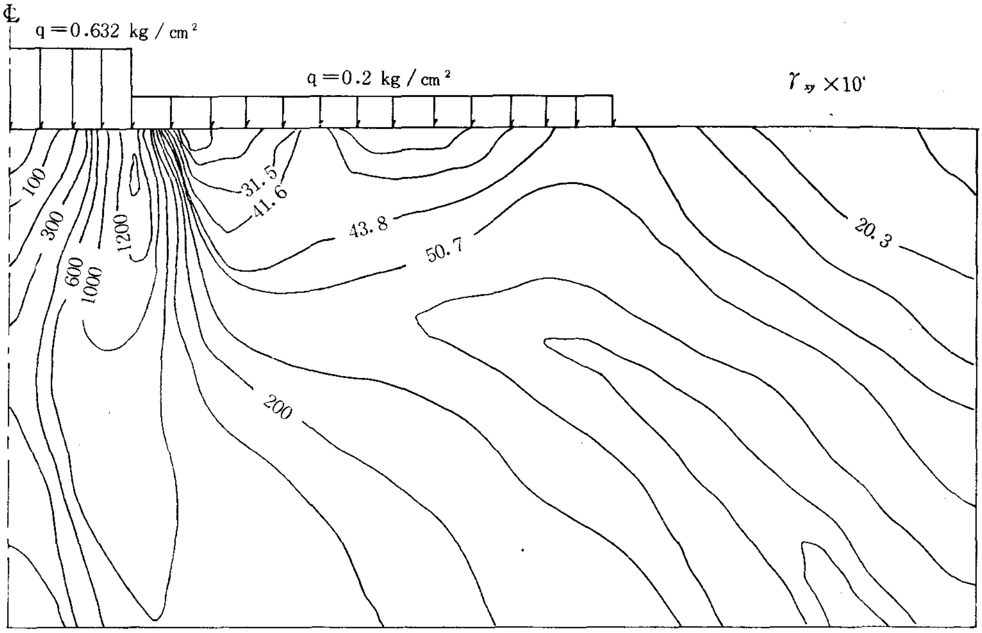

図8 (C) 点 の γ_{xy} 分 布

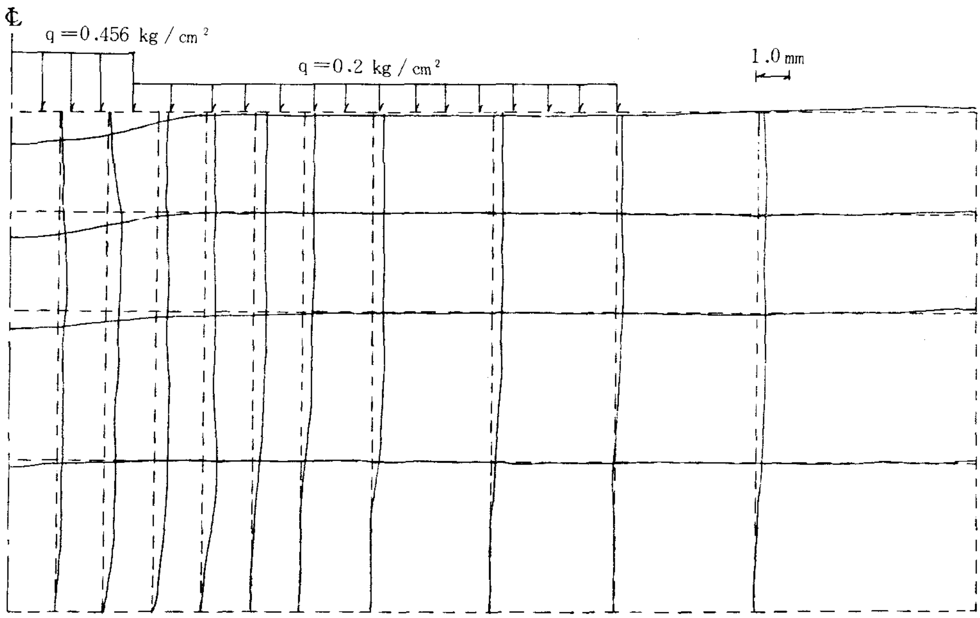

図9 (B) 点 の 節 点 変 位 U-V 量

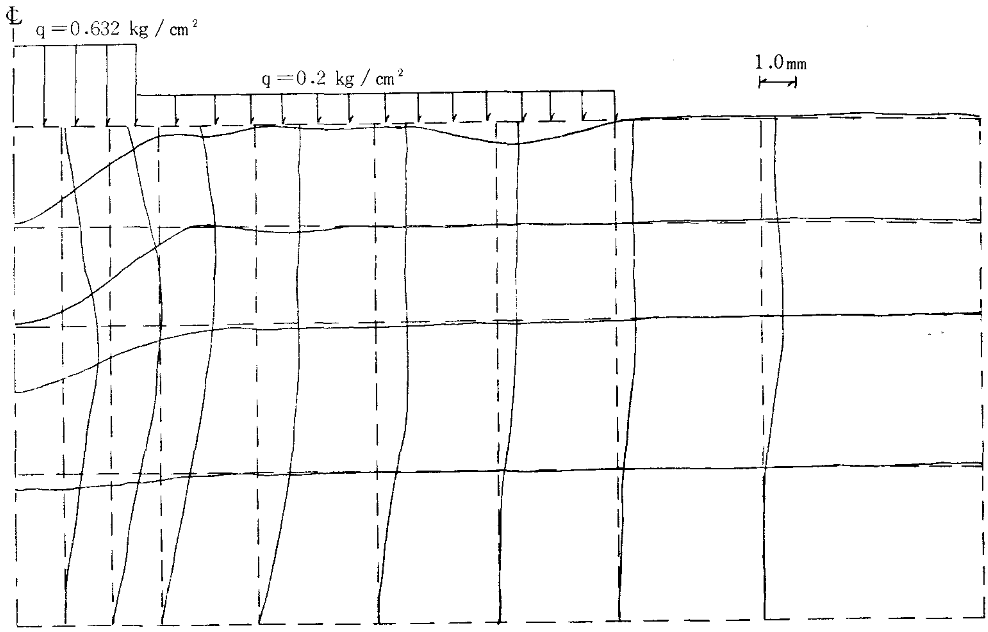

図10　(C) 点 の 節 点 変 位 *U*-*V* 量

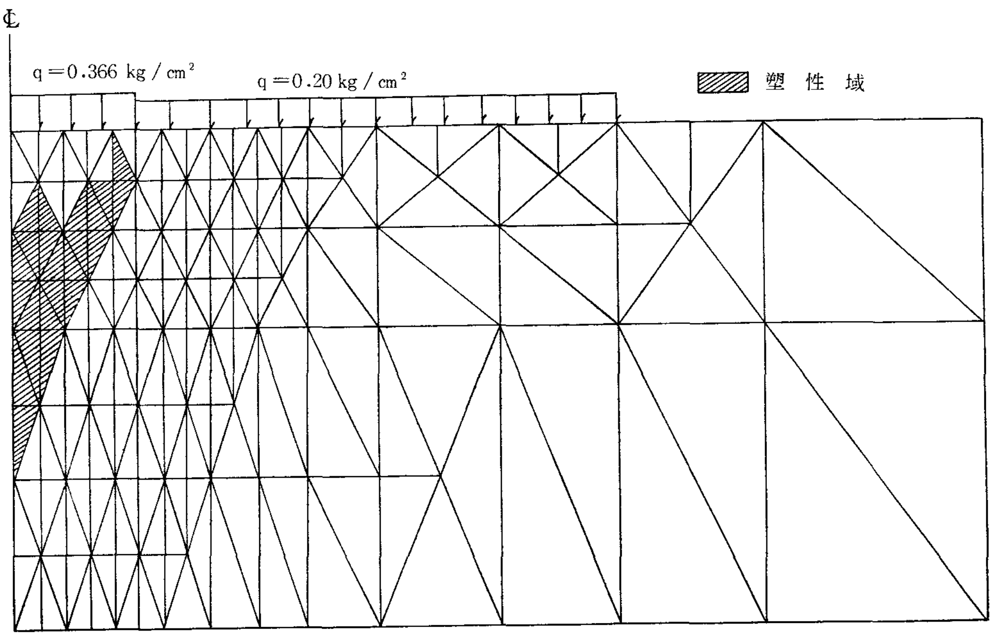

図11　(A) 点 の 塑 性 域 発 達 状 況

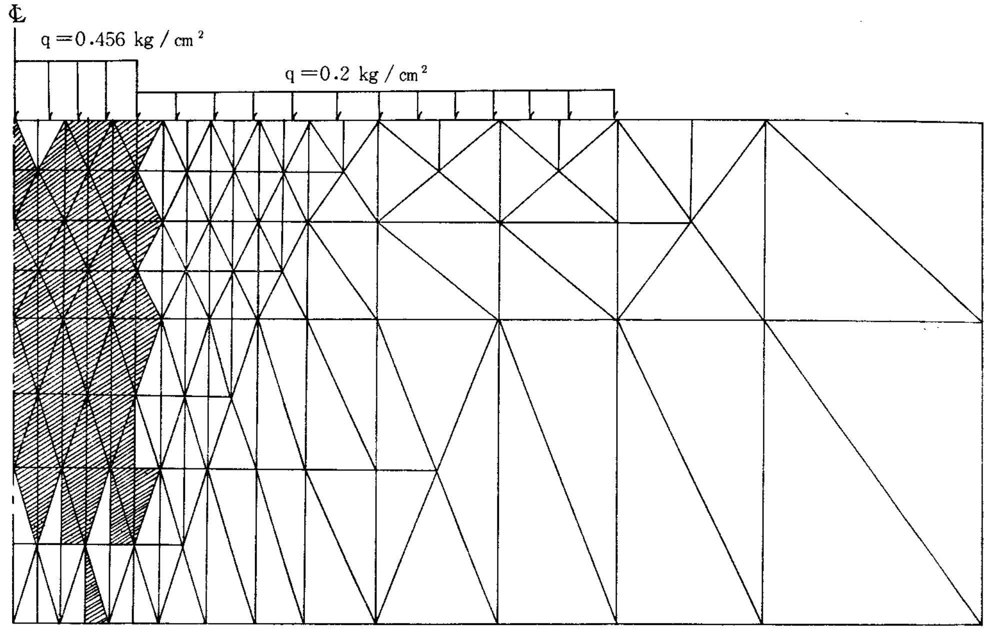

図12　(B) 点の塑性域発達状況

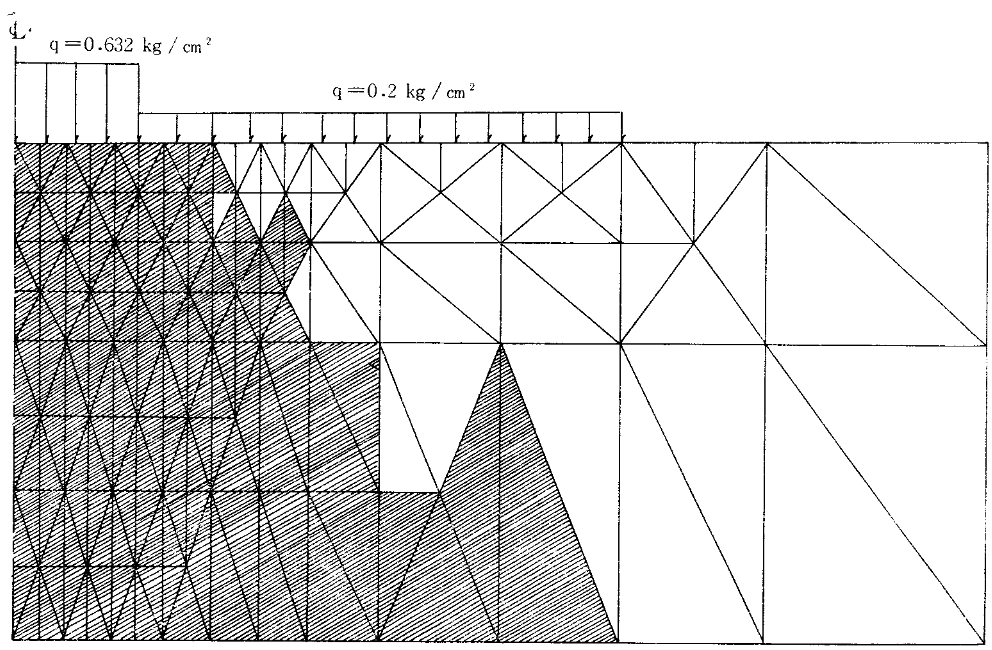

図13　(C) 点の塑性域発達状況

囲も広がっている。全般に等応力線が一様化している。図６は(A)点におけるせん断ひずみを示し，ひずみ値に大きな差はなく，荷重変化点でその集中をみる。又，荷重接点より出た等値線は押え荷重の影響をうけながら横方向に広がっている。図７は(B)点のγ_{xy}分布である。ひずみ値が先にくらべて２倍に増加している。又そのひずみ線が細かくなりせん断変形の著しい事がわかる。分布にかたよりがみられ複雑化している。図８は(C)点のγ_{xy}分布である。ひずみの集中によりせん断変形が著しくなり，ひずみ値も極限化してきている。ひずみ値の中心域が荷重変化点の上部付近にみられる。又，等ひずみ線の広がりも押え荷重の影響を受けながら全面にほぼ等しく広がっている。次に変位図について述べる。図９は(B)点における $U-V$ 節点変位量を示したものである。y方向変位量であるがやはり主荷重直下において最大値を示し，下方に向かい減少している。又 $q=0.2kg/cm^2$ 下ではその沈下量はわずかとなっている。又，図の右端では若干，上方への変位を示している。x方向変位量は，主荷重より，荷重接点付近で最大値を示し，右方向へ減少している。図10においては，(C)点での $U-V$ 変位量である。載荷量は50％の増加であるがy方向変位量は主荷重変位の増加量は３倍になり，又，x方向変位も同様の増加率を示している。又，x方向の変位は押え荷重下でも大きな変位量を出しているが，y方向変位は主荷重以外では $q=0.456kg/cm^2$ 図と大きな差はみられない。次に塑性域発達状況をみると刻々塑性域が広がっていくのが具体的に知る事が出来る。図11の(A)点での状況は主荷下においてクサビ状に塑性化しているのがわかる。又，図12の(B)点ではほとんど底辺近くまで発達している。図13の(C)点に到っては押え荷重下まで塑性域が広がり，変位量の増大からしても極限にいたっている。いずれも σ_y 分布図の形がそれぞれの説明をしている又値からすればγ_{xy}図も理解できる。このように地盤内の塑性域の分布からみると，とても円弧すべりなどとは考えられない事がわかる。軟弱地盤の基礎の破壊は載荷部直下の部分の塑性流動化が問題なのであって，それが生じるとその周囲の半無限地盤の側方への弾性圧縮によって基礎の破壊沈下が起こるという考え方のほうが的を射ているといえる。

§５　結　　　言

本稿の結論として次の事柄が言える。

(1) 弾性の問題における D^e を D^p におきかえるならば弾塑性問題の取扱いも全く同様であることがわかる。

(2) D^e と D^p を比較すれば，与えられたひずみ増分 $d\varepsilon_{ij}$ に対し，塑性変形がはじまって後の応力増分 $d\sigma_{ij}$ が弾性の場合に比較して小さくなることがよく理解出来る。

(3) せん断ひずみ増分に対応して降伏点を越て後は，応力のせん断成分ばかりでなく，垂直成分にも変化を生ずることがわかった。

(4) 軟弱地盤の基礎の破壊は載荷部直下の部分の塑性流動化が問題であり，それによる側方への弾性圧縮で基礎の破壊沈下が起ると考えられる。

地盤の弾塑性解析について以上述べて来たが，特に変形と破壊に着目して論じた。支持力や安定計算に用いられている，スベリ面による安定計算法は，現実の破壊の様相とも違っている。又，スベリ面が発生しても円弧ではなく，そのすべての点で同時に最大強さが発揮されるわけでもない，ということが明らかにされた。特にこの問題について考えるときには，進行性破壊という現象に着することが重要である，さらにこの問題をつきつめて論じていくと，つまりは，土のダイレイタンシー特性を取入れ，圧縮―引張り両域に適用される一般的な土の破壊基準や，応力-ひずみ関係が見いだされなければ，正しい解決は出来ない事が理解できた。一方，土の変形に関してもう一つ大きい物性は，それは時間依存特性であると言える。このような土の粘弾性的な応力-ひずみ-時間の関係を支配する法則が知られると，クリープを有限要素法に含めることができる。そして解に用いる土の構成法則に応じて種々の解法が開

発されているが，いずれの場合にもやはり重要なのは土の粘弾性挙動の特性の選択である。そのために，厳密な構成方程式を求めて用いたり，レオロジーモデルを用いてアプローチが行なわれているが，選ばれた粘弾性特性に対してもっともよい解析手法や要素形の選択に今後の研究の課題がある。本研究の数値計算は広島大学計算機センター HITAC-8700 を用いて行った。

最後に本研究の遂行にあたり，東京大学生産技術研究所，山田嘉昭教授より種々の助言と文献資料の提供を賜った。又，広島大学工学部，松島卓己助手より多大な御協力を得たので記して深謝する次第である。

参　考　文　献

1) H. Aboshi : Stabilty of Soft Clay Foundations Underneath Embankment, Consolidated by Means of Card-Board Drains. Soils and Foundations, vol. 9, No.2 p. 2—13, 1969

2) 網干・小堀：軟弱地盤の変形解析に関する基礎的研究．第28回土木学会中国四国支部大会一般講演概要集，p. 105, 1976

3) 山田：塑性力学．日刊工業新聞社，p. 66—95, 1965

4) Hill, R. : The mathematical Theory of Plasticity. Oxford Press, p. 47—85, 1950

5) 小堀・網干：地盤の変形解析に関する基礎的研究—2次元弾性解析—．呉高専研究報告，Vol. 12, №.2, March 1977

6) Y. Yamada : "Recent Japanese Developments in Matrix Displacement Method for Elastic-Plastic Problems", U.S.-Japan Seminar on Matrix Methods of Structural Analysis and Design, Tokyo (1969), to appear in the proceedings of the seminar.

7) Zienkiewicz, O.C. : The Finite Element Method in Engineering Science. Mc Graw-Hill, p. 53—59, 1971

(昭和52年6月21日受付)

鉄筋コンクリート筋違入骨組の実験的研究
（第2報）部材の性状に関して

（建築学科）福　原　安　洋

Experimental Study on Reinforced Concrete Braced Frames
(Report 2) On Characteristics of Members Composing a Frame

Yasuhiro FUKUHARA

In order to clarify the characteristics of reinforced concrete braced frames and members composing the frame, further five spesimens of one-storied and one-spanned reinforced concrete braced frame with about one-tenth scale were tested.

This report intend to clarify mainly the characteristics of members composing a frame.

And expansion and contraction, secondary stress and strength of members, and also the relation between the axial force lebel of the member composing a flame and the ductility of the frame were showed and discussed.

§1 緒　言

第1報では，一層一スパンの鉄筋コンクリート筋違入骨組の実験を行い，骨組の剛性，耐力，変形に関して検討し，鉄筋コンクリート筋違入骨組が，耐震要素としての十分な性能を有することを明らかにし，かつ節点をピンとしたトラスとしての計算値がほぼ一致することを示した。

今回は，さらに4コの鉄筋コンクリート筋違入骨組と，1コの耐震壁の計5コの試験体による実験を行い，前回の実験結果と合せて，骨組を構成する部材の性状の検討と骨組の靭性に関する検討を行った。

§2 実験概要

試験体の形状で前回と異なる所は，3コの試験体の筋違断面を大きくし，終局破壊が筋違の圧縮破壊によらないようにした点，又，耐震壁もそれに合せて，壁厚を大きくした点である。

又，配筋方法は，節点での定着法としてボルト型を採用しており，筋違の主筋としては，

表1　試験体一覧表

	柱，はり断面		筋違断面		柱頭軸力	接合部
	$b\times D$cm	鉄筋（P_g%）	$b\times D$cm	鉄筋（P_g%）	（kg/cm²）	配筋型
BHp-III	10×10	4-9ϕ(2.08)	7×7	4-9ϕ(4.16)	40	ボルト型
BHp-IV	〃	〃	10×7	4-9ϕ(4.16)	〃	〃
BHp-V	〃	〃	〃	1-19ϕ(4.1)	〃	〃
BHp-VI	〃	〃	〃	2-D^{10}(3.63)	〃	普通フック
W-II	〃	〃	t_w=35　2-3ϕ@25		〃	〃

鉄筋量がほぼ2％のもの3種類を用いそれらの差の検討を試みた。さらにBH_p-Ⅲ は断面は前回と同様であるが，筋違のフープとして，3φ@10の円形スパイラルフープを用いている。以上の試験体一覧表を表1に示す。

なお，材料の性質は表2に示す。

表2　　材　料　の　性　質

鉄筋				コンクリート				
	断面積	σ_y t/cm^2	σ_{max}	W/C	スランプ	F_C	E	最大骨材
9φ	0.57	3.39	4.65	75%	20.5cm	kg/cm^2 290	kg/cm^2 $\times 10^5$ 2.16	5mm
3φ	0.083	2.52	3.83					
2φ	0.035	2.02	2.74					
19φ	2.3	3.57	5.09					
D13	1.27	3.57	5.38					

実験方法は，前回と同様であり，柱頭に40kg/cm^2の一定軸力を加えた状態で，正負繰り返しの水平加力を行った。

表3　　結　果　表

試験体	弾性剛性		ひびわれ荷重		ひびわれ時の部材角		降伏荷重		降伏時の柱部材角		最大荷重	最大荷重時柱部材角
	実験	計算	実験	計算	実験	計算	実験	計算	実験	計算	実験	実験
BH_p-Ⅲ	t/cm 3.5×10^2	t/cm 2.8	t 6	t 9.7	$\times 10^{-3}$ 0.28	$\times 10^{-3}$ 0.53	t 36	t 33.4	$\times 10^{-3}$ 3.1	$\times 10^{-3}$ 3.8	39 t	$\times 10^{-3}$ 5.3
BH_p-Ⅳ	3.9	3.52	4	12.9	0.23	0.60	34	34.3	2.9	3.3	37.4	15.0
BH_p-Ⅴ	4.0	3.52	6	12.0	0.25	0.58	34	35.2	3.3	3.3	37.9	12.5
BH_p-Ⅵ	4.0	3.36	8	10.6	0.33	0.50	34	36.4	3.6	2.7	36.0	10.0
W -Ⅱ	3.9	3.13	10	11.8	0.51	0.4	28	25.1	3.2		32.0	9.1

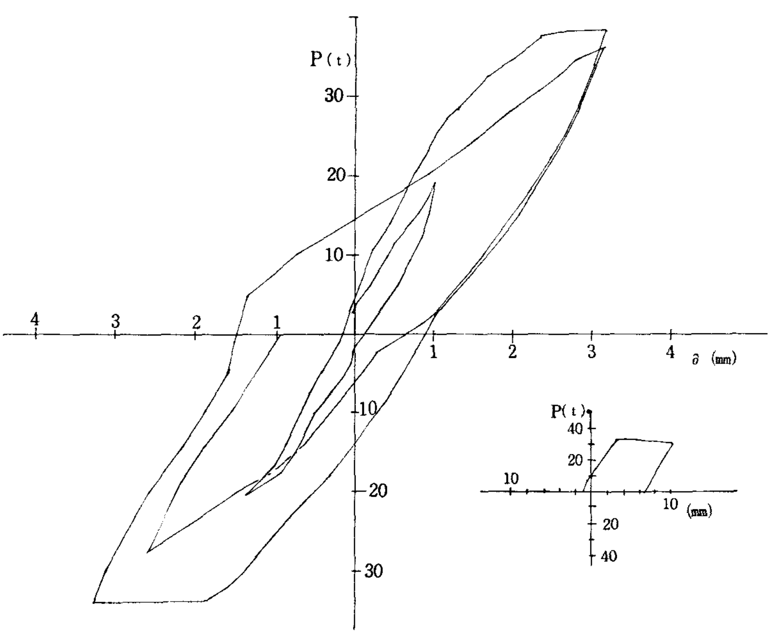

図1　荷重ーたわみ曲線（BH_p-Ⅲ）

その結果一覧表を表３に，荷重―たわみ曲線を図１～５に，さらに，ひびわれ及び破壊の状況を図６に示す。

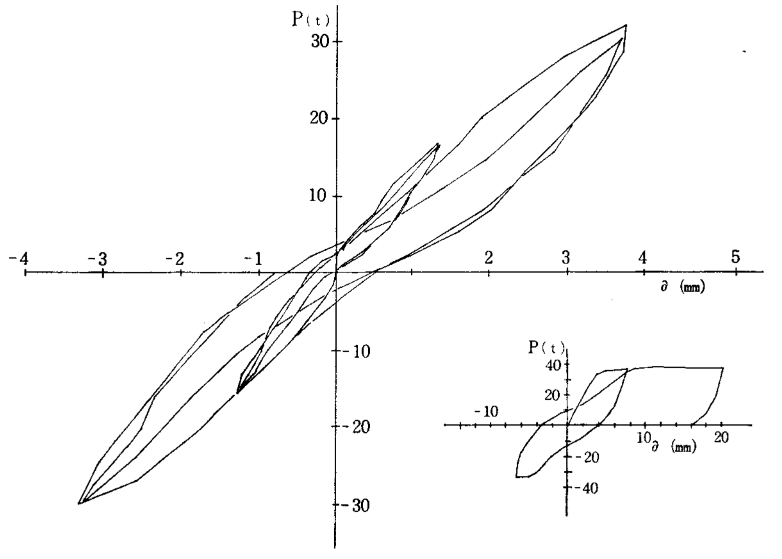

図２　荷重―たわみ曲線（*BHp*-Ⅳ）

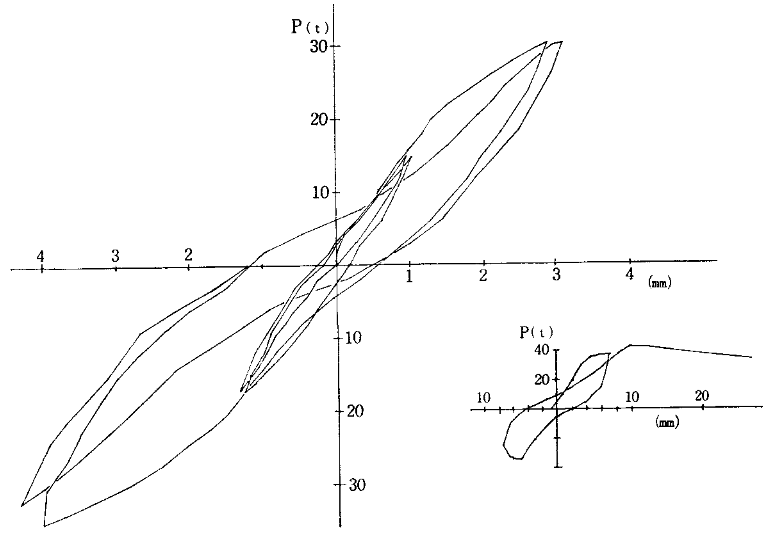

図３　荷重―たわみ曲線（*BHp*-Ⅴ）

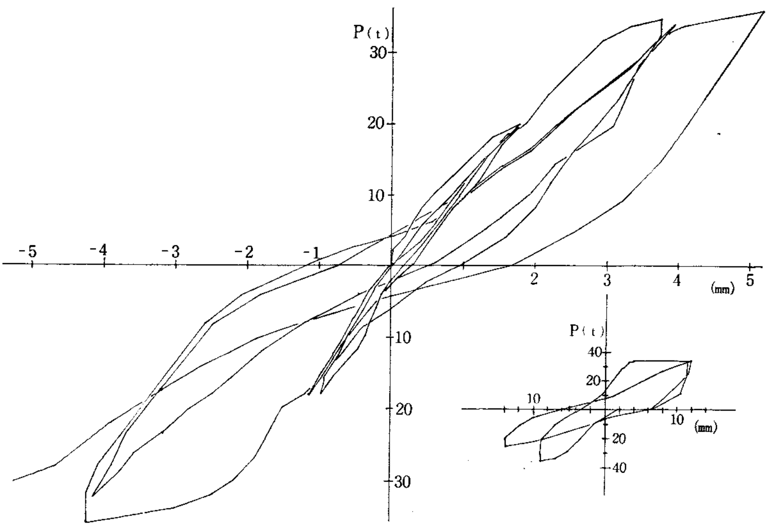

図4　荷重―たわみ曲線（*BHp*－Ⅵ）

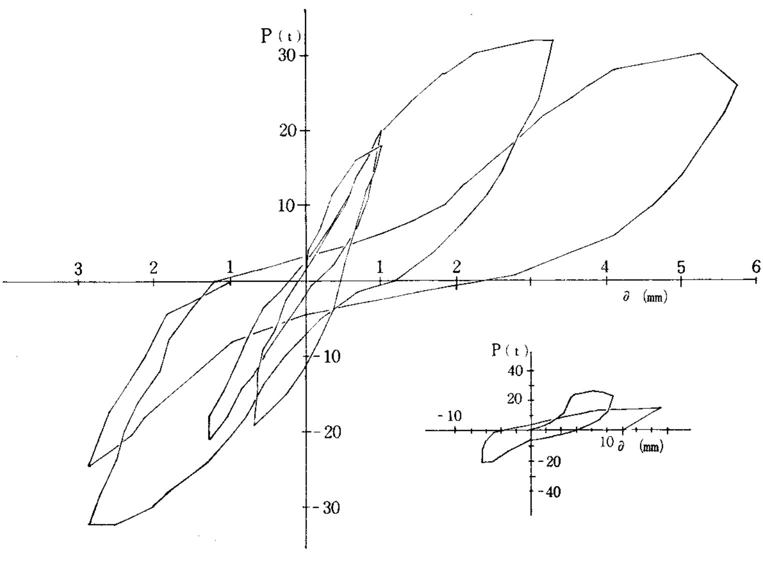

図5　荷重―たわみ曲線（*W*－Ⅱ）

以上の破壊経過は，前回とほぼ同様であるが，降状は引張材の主筋の降伏により起り，その後，最大耐力まで約10％の耐力上昇し，十分な靱性を示して終局に至っている。

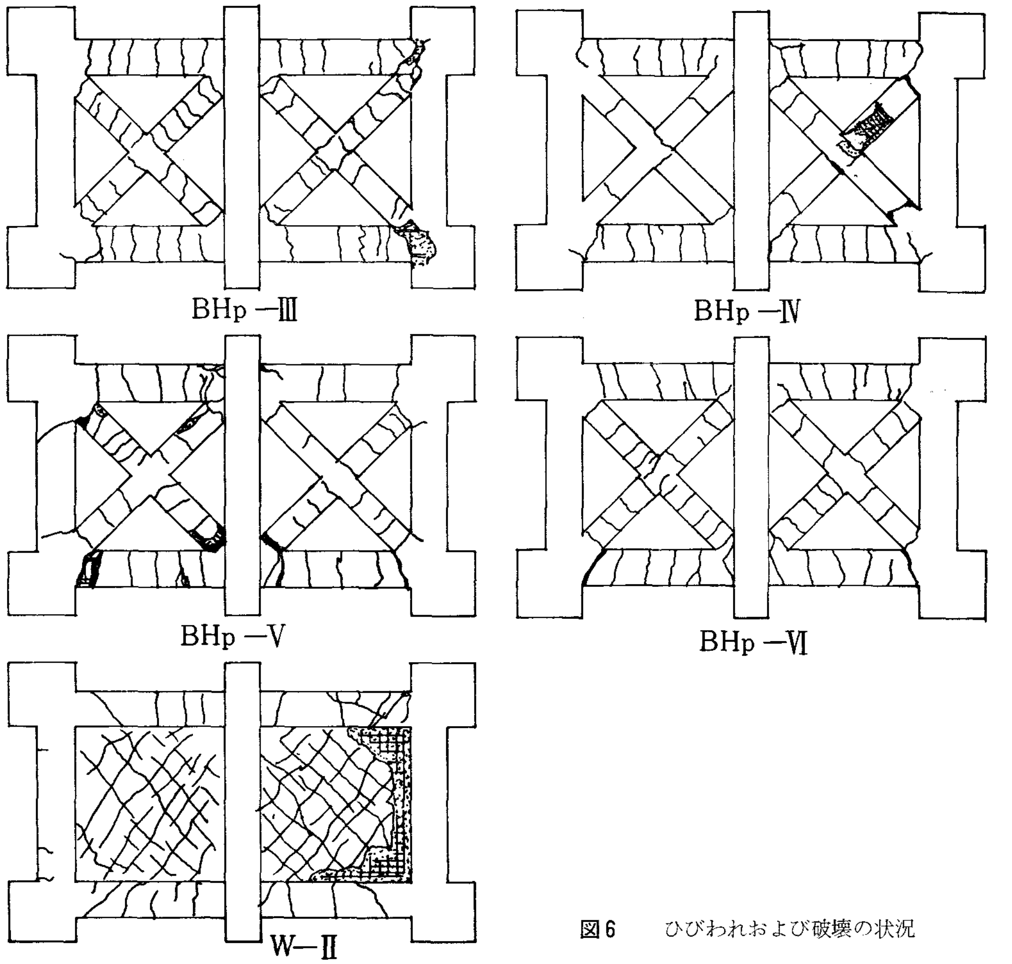

図6　ひびわれおよび破壊の状況

§3　検討及び考察

3.1　部材の伸縮

ここで言う部材の伸縮は，筋組の節点間の BH_p-Ⅳ の場合を図7に示すが，この図より柱材では，ひびわれの発生は明確である。又，繰り返し伸縮する際，引張力により大きいひびわれの生じた部材は，圧縮力を受けてもそのひびわれは密閉せず，残留伸びとして表われていることがわかる。そのため，伸縮は繰り返しの際，正の伸びの方に片寄った傾向を示している。一方筋違材は，両柱材の影響を受け，正負荷重ともほぼ対称の伸縮を示すが，伸び量は残留ひびわれのため大きい値を示している。

3.2　部材耐力と2次応力

節点を剛として計算した骨組の応力図を図8に示すが，ひびわれ前の2次応力（曲げモーメント）は小さいが，ひびわれ発生後はかなり大きい値を示す。又，筋違材は，柱材に比べ断面が小さいこともあり，2次応力は非常に小さい。

2次応力が最も大きいのは柱材脚部であるが，軸力による応力度 $\sigma_N kg/cm^2$ と，曲げによる応力度 σ_M kg/cm^2 の比 σ_M/σ_N は，骨組の降伏耐力付近では，2～3程度になる。又，部材のせん断応力度は $\tau=10$ kg/cm^2 以内であり，コンクリート強度の1/20以下の小さい値を示す。

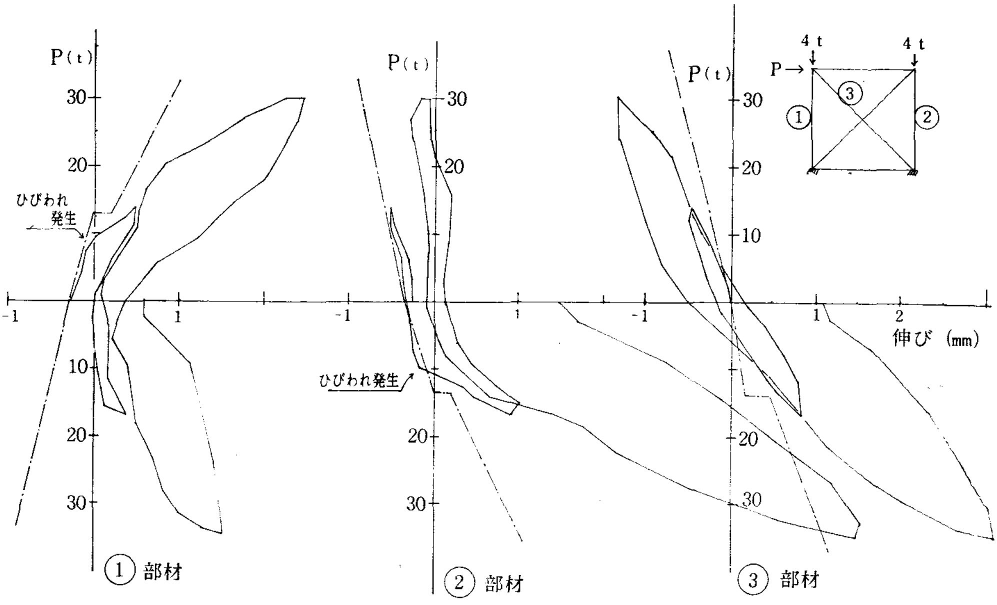

図7　部　材　の　伸　縮

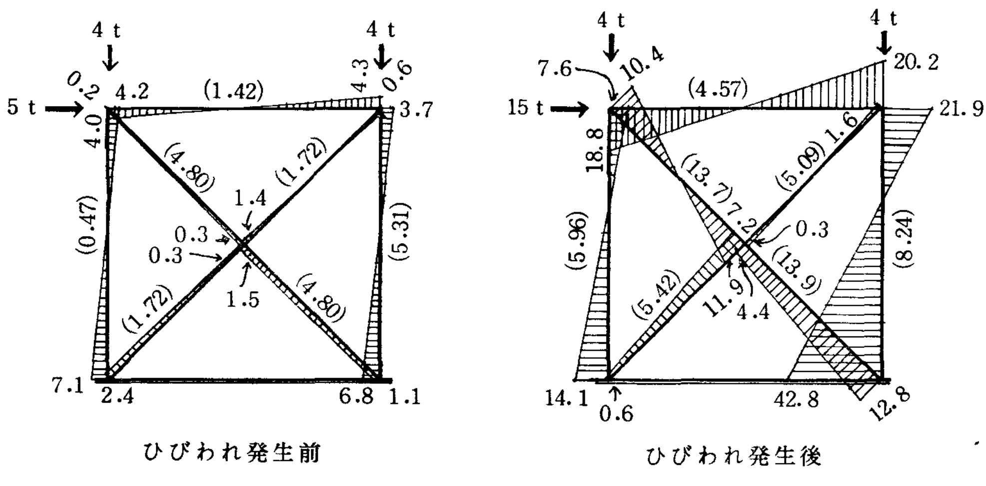

図8　応　力　図（曲げモーメント（$t\,cm$），（　）内は軸力（t））

次に，軸力と2次応力との関係をみるため，BH_p-Ⅰ の場合を図9に，N/BD-M/BD^2 図として示した。

この図より，ひびわれ発生後は急に2次応力が大きくなることがわかる。

又，図9には，鉄筋コンクリート柱の塑性耐力略算法[1] によって計算した値を記入してあり，部材応力線と交叉する点が部材耐力を示すことになる。この図より圧縮耐力は，単純圧縮耐力に比べ，筋違材では約65～75％の耐力になることがわかる。又，BH_p-Ⅰ の場合は，引張材の主筋降伏と，圧縮材の降伏がほぼ同時に生じることも推定できる。

3．3　部材応力度と骨組の靱性

前報及び今回に報告した試験体は，いずれも圧縮部材の応力度が大きく，靱性に関しては十分でないものもある。そこで，骨組の塑性率と部材応力度の関係を筆者らが行った過去の実験結果をも含めて示

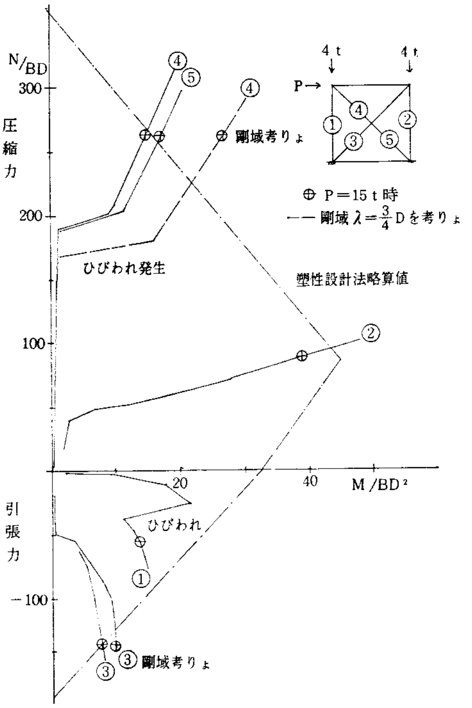

図９　N/BD–M/BD^2図BH_p－Ⅰ）

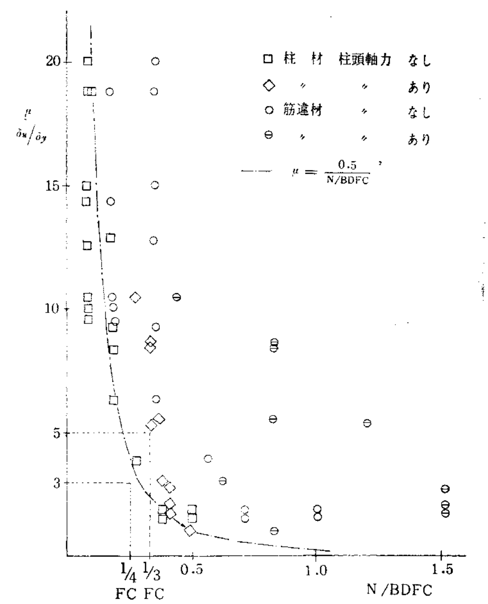

図10　圧縮材部材軸応力度と骨組の塑性率

したのが図10である。図中，鎖線で示したものは岡田博士の柱材単独の実験式[2]である。これを見ると骨組の靭性は柱材単独の実験式にほぼあてはまることがわかる。

又，$N/BDFC<1/3$ の応力度の部材で構成した骨組は，塑性率３を $N/BDFC<1/4FC$ の場合は塑性率５を確保できることがわかる。

さらに，$N/BDFC$ の小さい場合に，岡田博士の実験式に比べ靭性がないが，これは部材の材端拘束の影響の差と考えられる。

3．4　部材の配筋について

今回の実験では，筋違材の配筋を各種行った。まず，BH_p-Ⅲ，BH_p-Ⅴ では，フープを3φ@10と非常に密に用いたが，結果的にはコンクリートの充てんの不良のカ所があり，靭性の増大の効果がなかった。このことは，フープ増と施工性に関する問題であり，接合部での配筋と同様，検討の必要がある。

次に1-19φ，2-D13という太径鉄筋を用いたが，4-9φ の場合との差は認められなかった。ただ，2-D13を用いたものは，定着形式が普通フックであるので，接合部内での配筋の混雑によるコンクリートの充てん不良となったためと考えられる接合部内での定着破壊を生じた。

§４　結　　言

鉄筋コンクリート筋違入骨組は，耐震壁に劣らない耐震性能を有することのみならず，簡単なトラス計算によってその剛性等を把握できることなど，建築の耐震要素として大いに利点のあることを示した。

今後は，接合部の設計法，プレキャスト化などの施工法も含めて検討を行う必要がある。

最後に，御指導，御助言を頂いた広島大学嶋津博士に深謝いたします。

文　　献

1）日本建築学会：鉄筋コンクリート構造計算規準同解説

2）岡田恒男：軸力と水平力を同時に受ける鉄筋コンクリート柱の水平変形限度に関する研究．日本建築学会論文報告集，No.103（昭39.10）

（昭和52年5月31日受付）

正弦波地動に対する1質点系建物の弾塑性近似応答式について

(建築学科) 門 前 勝 明

Approximate Response Prediction of Elasto-plastic Single-degree-of-freedom System Subjected to Sinusoidal Ground Motion

Katsuaki MONZEN

Based on energy input into a structure by sinusoidal excitation and energy of deformation, approximate response prediction of elasto-plastic single-degree-of-freedom system from elastic response spectrum is proposed.

Relation of yield strength of the spring and ductility factor was determined and showed good agreement with the result of which was solved by a Runge-Kutta procedure.

§1 緒 言

既報[1),2)]で1質点系完全弾塑性モデルの正弦波地動による構造物へのエネルギー入力特性と構造物のエネルギー吸収特性について述べた。この報告は，構造物へのエネルギー入力特性と構造物のエネルギー吸収特性より，弾性応答値から近似的に弾塑性応答値を求める関係式について述べようとするものである。

§2 解 析 方 法

図1に示す1質点系構造物が地震動をうけた場合，質点の運動方程式は次式で与えられる。

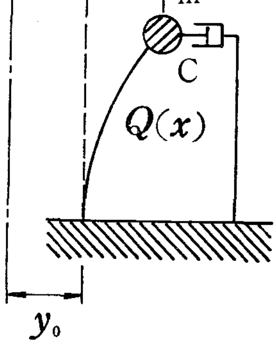

図1 解析モデル

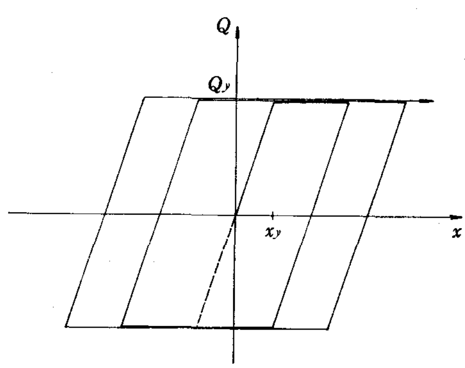

図2 復元力特性

$$m\ddot{x}+C\dot{x}+Q(x)=-m\ddot{y}_0 \qquad (1)$$

ここで，x＝基礎に対する質点の変位

m＝質点の質量

C＝減衰係数

$Q(x)$＝復元力

$\ddot{y}_0$＝地震加速度

この報告では，構造要素の非線形特性として図２に示す完全弾性モデルを使用する。完全弾塑性モデルは鋼構造剛接骨組などで代表される紡錘型履歴特性を有する構造物には比較的よく適合するが，鉄筋コンクリート構造物などで代表される変位の増大などによって固有ループの剛性が低下する履歴特性を有する構造物にはよいモデルとは言えない[3]。しかし，完全弾塑性モデルは構造物の履歴特性を表わす代表的モデルであり，地震動による構造物の塑性挙動を評価するという観点に立てば，完全弾性モデルによる応答解析結果から得られた情報は，一般的構造物が大地震を受けた場合の非線形挙動を評価する上で参考になるものと考えられる。

$q(x)=Q(x)/m$

$\omega_0=\sqrt{K/m}$：減衰がない場合の弾性固有振動数

K＝弾性バネ定数

$h=C/2m\omega_0$：減衰定数

以上の関係式により，(1)式はつぎのように書き直すことができる。

$$\ddot{x}+2h\omega_0\dot{x}+q(x)=-\ddot{y}_0 \qquad (2)$$

(2)式はルンゲークッタ法で解くことができる。この結果を以後数値計算結果と呼ぶことにする。(2)式の両辺に $dx=\dot{x}dt$ をかけ地震の継続時間 t にわたって積分すれば質点に作用している力による単位質量当りの仕事（エネルギー）の関係式が得られる[4)~6)]。

$$\int_0^t \ddot{x}\dot{x}dt+2h\omega_0\int_0^t \dot{x}^2dt+\int_0^t q(x)\dot{x}\ dt=-\int_0^t \ddot{y}_0\dot{x}\ dt \qquad (3)$$

(3)式で，左辺第１項は質点の運動エネルギー $E_k=1/2\dot{x}^2$，第２項は減衰機構によって吸収されたエネルギー E_D，第３項はバネ系の塑性歪によって吸収されたエネルギー $E_{p\cdot d}$ と弾性歪エネルギー E_R の和である。この弾性歪エネルギーと運動エネルギーの和が系に残っている弾性振動エネルギーである。右辺は地震外力による系への総エネルギー入力 EI で，これらの各エネルギー間には次の関係式が成り立つ。

$$EI=E_k+E_R+E_D+E_{p\cdot d} \qquad (4)$$

この報告では，力入地震波として最大加速度１gの正弦波10秒間を使用する。完全弾塑性系の弾性固有周期 T_0 は 0.5秒に固定し，減衰は無視（$h=0.00$）する。正弦波地動の振動数 ω は，構造物の弾性固有振動数 $\omega_0=2\pi/T_0$ と地動の振動数 ω の比 $\lambda(\lambda=\omega/\omega_0)$ が 0.15 から 0.8 までを 0.05 きざみの14種類，0.8 から 1.6 までを 0.1 きざみの８種類，合計22種類とした。完全弾塑性モデルの降伏せん断力 Q_y（図２参照）は線形最大応答せん断力 Q_e によって適当に変化させた。この報告は，主に線形最大応答量から近似的に降伏せん断力 Q_y に対応する最大変形 x_{max} を求める関係式を見い出すことを目的としているので，出力として次のものを考える。(1)運動エネルギーの最大値 $KE=\frac{1}{2}\dot{x}^2{}_{max}$，(2)ひずみエネルギー $E_s=Q_y(x_{max}-0.5x_y)=Q_yx_y(\mu-0.5)$，ここで，$x_y$；降伏変位（図２参照），$\mu=x_{max}/x_y$；ductility factor，(3)半サイクル間で塑性ひずみによって吸収されたエネルギーの最大値 PDO，(4)半サイクル間（図３ａｂｃ）に系が保有したエネルギーの最大値 $EIO=[E_k+ひずみエネルギー A]_{max}$。ここに，$A$

は図３ａｂｃｄで囲まれる面積で表わされる。EIO は近似的にａｂc′d′で囲まれた面積で表わすことができる。系が弾性の場合，EIO は近似的に $\frac{1}{2}\omega_0^2x^2_{max}$，又は $\frac{1}{2}\dot{x}^2_{max}$ とみなせる。

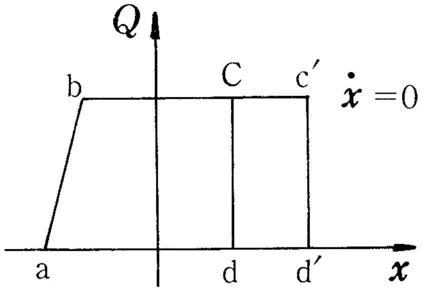

図　3

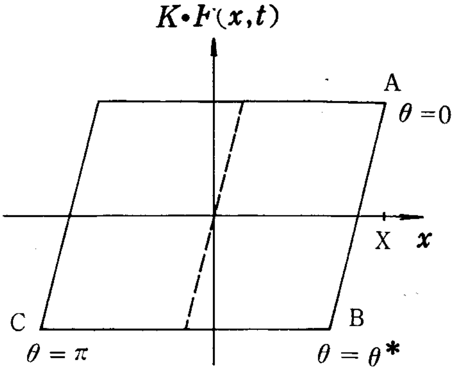

図4　定常状態の履歴特性

§3　定常振動

地動が正弦波の場合，近似的に弾塑性定常振動応答特性を得ることが可能である[7)~9)]。

正弦波地動を受ける１質点系弾塑性モデルの運動方程式は次式で与えられる。

$$m\ddot{x}+C\dot{x}+KF(x,t)=-mP\cos(\omega t+\varphi) \tag{5}$$

図４で定常振動は A から始まって B，C に至る半周期振動の繰り返しであると考えられる。

$$\left.\begin{aligned}F(x,t)&=x-(X-x_y) && 0\leqq\theta<\theta^*\\ &=-x_y && \theta^*\leqq\theta\leqq\pi\end{aligned}\right\} \tag{6}$$

(5) 式の解を近似的に正弦波とし，復元力関数 $F(x,t)$ をフーリエ級数に展開し１次項のみを取り上げれば次式が得られる。

$$x=X\cos\omega t \tag{7}$$

$$F(X\cos\theta,\theta)=X(C_1\cos\theta+S_1\sin\theta) \tag{8}$$

ここで，$\theta=\omega t$

$$\left.\begin{aligned}C_1&=\frac{1}{\pi X}\int_0^{2\pi}F(X\cos\theta,\theta)\cos\theta\,d\theta\\ S_1&=\frac{1}{\pi X}\int_0^{2\pi}F(X\cos\theta,\theta)\sin\theta\,d\theta\end{aligned}\right\} \tag{9}$$

$$\theta^*=\cos^{-1}\left(1-\frac{2x_y}{X}\right) \tag{10}$$

(6) 式を (9) 式に代入すれば，C_1 と S_1 が得られる。

$$\left.\begin{aligned}C_1&=\frac{1}{\pi}\left(\theta^*-\frac{1}{2}\sin 2\theta^*\right), && \frac{X}{x_y}>1\\ &=1 && \frac{X}{x_y}<1\\ S_1&=-\frac{1}{\pi}\sin^2\theta^*=-\frac{4}{\pi}\frac{x_y}{X}\left(1-\frac{x_y}{X}\right), && \frac{X}{x_y}>1\\ &=0 && \frac{X}{x_y}<1\end{aligned}\right\} \tag{11}$$

(7)式，(11)式を(5)式に代入し，$\sin\omega t$，$\cos\omega t$ の係数を比較すれば次の関係を得る。

$$(KC_1-m\omega^2)X=-mP\cos\varphi$$

$$(-C\omega+KS_1)R=mP\sin\varphi$$

$$\therefore X=\frac{P}{\omega_0{}^2}\frac{1}{\sqrt{\left\{C_1-\left(\frac{\omega}{\omega_0}\right)^2\right\}^2+\left(S_1-2h\frac{\omega}{\omega_0}\right)^2}}$$

$h=0$ の場合，

$$X=\frac{P}{\omega_0{}^2}\frac{1}{\sqrt{\left\{C_1-\left(\frac{\omega}{\omega_0}\right)^2\right\}^2+S_1{}^2}}$$

$$\left(\frac{\omega}{\omega_0}\right)=C_1\pm\sqrt{\left(\frac{x_y}{X}\cdot\frac{P}{x_y\omega_0{}^2}\right)^2-S_1{}^2} \tag{12}$$

共振振動数は(12)式が等根をもつ場合であるから，

$$\frac{\omega}{\omega_0}=\sqrt{C_1} \tag{13}$$

共振振幅に対して，

$$\frac{P}{x_y\omega_0{}^2}=\frac{4}{\pi}\left(1-\frac{x_y}{X}\right) \tag{14}$$

$$=\frac{4}{\pi}\left(1-\frac{1}{\mu}\right)$$

が成立する。

§4　定常振動計算結果と数値計算結果の比較

図5は定常振動計算結果（図中の曲線）と数値計算結果（図中の Mark）の比較を外力レベル $F=P/x_y\omega_0{}^2$ をパラメータに μ と λ の関係（共振曲線）で示したものである。全体の傾向は比較的よく一致しているが，定量的には共振点付近を除けば，よく一致しているとは言えない。この差は定常振動の近似計算による誤差ではなく，過度振動による影響と考えられる[10]。図12に定常振動結果と数値計算結果（図中白まる）の比較を λ 別に Q_y/Q_e と μ の関係で示す。Q_yを$Q_{e\cdot c}$（数値計算による線形最大応答せん断力）で無次元化した場合（図中点線），数値計

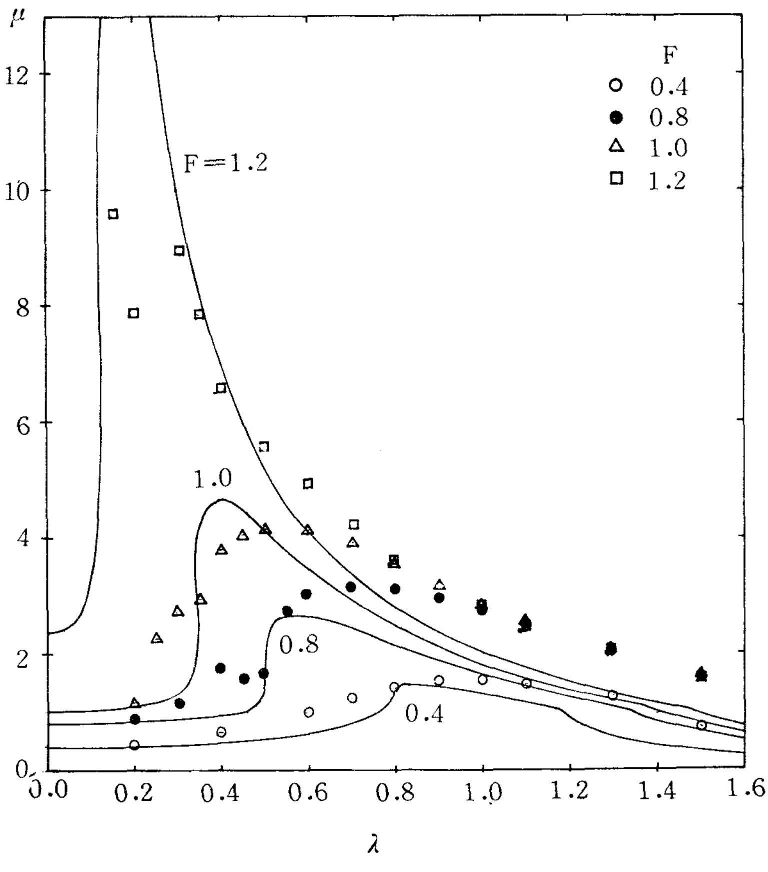

図5　共　振　曲　線

算結果と定常振動結果は$\lambda=1.0$（図12-5参照）付近で比較的よく一致するが，他のλについて，定常振動結果は数値計算結果に比較して全般的に小さな応答量を与える。これは耐震設計を対象にした場合，危険側の値を与えることになるので不都合である。同様に，Q_yを$Q_{e\cdot s}$（定常振動による線形最大応答せん断力）で無次元化した場合の関係を1点鎖線で示す。但し，数値計算結果のQ_yは$Q_{e\cdot c}$で無次元化したままである。定常振動結果と数値計算結果は約$\lambda\geqq0.8$で比較的よく一致するが，$0.2<\lambda\leqq0.6$で定常振動結果の方が全般的に大きな応答量を与える。$\lambda=0.2$の場合（図12-1参照），定常振動結果はμが小さい範囲で小さな応答量を与え，μが大きい範囲で大きい応答量を与える。以上の結果から，定常振動応答値と数値計算結果は過度振動の影響などで定性的には比較的よく一致するが，定量的には共振点付近を除いて良く一致するとは言えない。

§5　弾塑性近似応答式の算定

既報[2)]で降伏せん断力の変化による入力エネルギー特性と系によって吸収されるエネルギーE_sを適当に近似できれば，入力エネルギーと系の吸収エネルギーを等置することで系の最大応答変形を近似的に得ることができることを述べた。以下の解析方法は既報の結果を発展させたものである。

5.1　半サイクル間に系が保有したエネルギーの最大値*EIO*の算定と系の吸収エネルギー

図11に$Q_y/Q_{e\cdot c}$とEIO/EEI（ここでEEIは系が弾性の場合，系が保有したエネルギーの最大値を示す）の関係を示す。Q_y-EIOの特性はλによって図6に示す3種類に分けられる。既報[2)]の研究結果より次の結論を得た。

(1)　λが比較的小さい場合（図6-1，2参照），

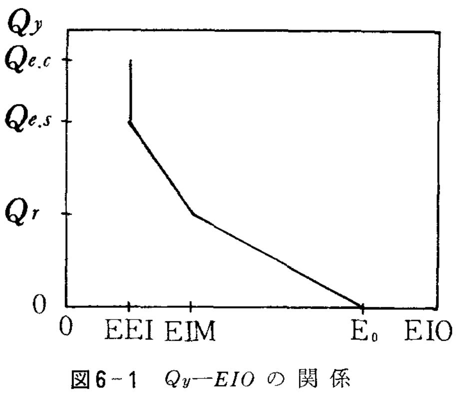

図6-1　Q_y—EIOの関係

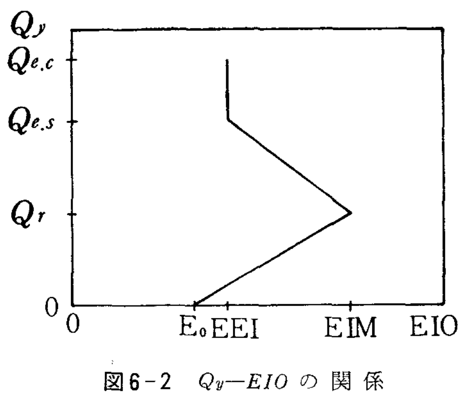

図6-2　Q_y—EIOの関係

$$EIO\fallingdotseq EEI,\quad 但し,\quad Q_y\geqq Q_{e\cdot s}\qquad(15)$$

$$EIO\fallingdotseq\frac{EIM-EEI}{Q_r-Q_{e\cdot s}}Q_y+\frac{EEI\cdot Q_r-EIM\cdot Q_{e\cdot s}}{Q_r-Q_{e\cdot s}}$$

$$但し,\quad Q_{e\cdot s}\geqq Q_y\geqq Q_r\qquad(16)$$

$$\fallingdotseq\frac{EIM-E_0}{Q_r}Q_y+E_0,\quad 但し,\quad Q_r\geqq Q_y>0\qquad(17)$$

ここで，Q_r；共振振幅を与える降伏せん断力，EIM；Q_rに対応するEIOで，図6-2の場合最大値，E_0；Q_yがゼロ近傍に対応するEIO。

(2)　λが大きい場合（図6-3参照），

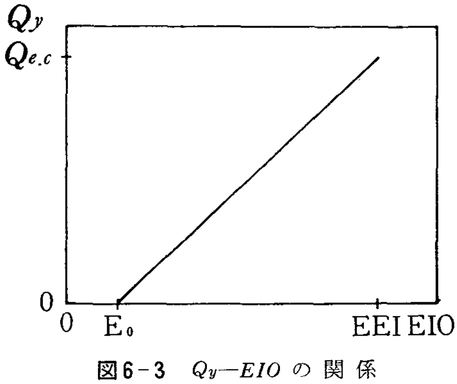

図6-3　Q_y—EIOの関係

$$EIO \doteqdot \frac{EEI-E_0}{Q_{e\cdot c}}Q_y+E_0,\quad 但し,\quad Q_y>0 \tag{18}$$

$Q_y/Q_{e\cdot c}$ が非常に小さい場合，バネ系の剛性は近似的に塑性部分の剛性と考えることができるから，$h=0$ の場合，(1)式より，

$$(\ddot{x}+\ddot{y}_0)=-\frac{Q_y}{m}$$

$$\dot{x}+\dot{y}_0=-\frac{Q_y}{m}t+C_{co},\quad (C_{co}=一定) \tag{19}$$

となる。$t=0$で，$\dot{x}(0)=0$，$\dot{y}_0(0)=[\dot{y}_0]_{t=0}$ とすれば，$C_{co}=[\dot{y}_0]_{t=0}$ となる。ここで，完全弾塑性の場合，塑性部分の剛性はゼロであるから近似的に $\dot{x}(0)\doteqdot\dot{y}_0(0)\doteqdot0$ とみなせることより $C_{co}\doteqdot0$ となる。従って(19)式は，

$$\dot{x}+\dot{y}_0=-\frac{Q_y}{m}t \tag{20}$$

となる。(20)式の右辺は Q_y が非常に小さい場合，有限の t に対しゼロとなるから，

$$\dot{x}\doteqdot-\dot{y}_0$$

となる。(3)式の右辺より，

$$-\int_0^t\ddot{y}_0\dot{x}dt\doteqdot\int\ddot{y}_0\dot{y}_0dt=\frac{1}{2}\dot{y}_0^2 \tag{21}$$

となることより，$[EIO]_{Q_y\to0}=E_0$ は近似的に次式で与えられる。

$$E_0=\frac{1}{2}[\dot{y}_0]^2_{max} \tag{22}$$

本報告書の場合，$\dot{y}_0=\frac{1}{\omega}980\cos\omega t$ となるので，E_0 は系の固有振動数とは無関係に次式で与えられる。

$$E_0\doteqdot\frac{1}{2}\left(\frac{980}{\omega}\right)^2 \tag{23}$$

定常振動の場合，EIO は次式で与えられる。

$$EIO=\frac{{Q_y}^2}{{\omega_0}^2}(2\mu-1.5) \tag{24}$$

図７の曲線は(13)，(14)式より μ に対応する共振振動数 λ と Q_y を求め，(24)式に代入したものである。図中の EIM は数値計算結果による極大値である。$0.35\leqq\lambda\leqq0.7$ の範囲で，定常共振解と数値計算結果はよく一致していることがわかる。

EIO が最大値を持つ条件は，EIM が EEI より大きく且つ E_0 が EIM より小さくなければならない。図７の１点鎖線は E_0 と λ の関係を示す。$\lambda\leqq0.2$ の場合，E_0 は EIM より大きいことがわかる。これが $\lambda<0.35$ の場合，Q_y-EIO 特性に明確な最大値又は極大値が表われない理由と考えられる。

図７より，Q_y と EIO の関係が(2)の場合（図6-3参照）に対応する λ の範囲は EEI と図中の曲線との交点（$\lambda\doteqdot0.7$）以上とみなすことができそうであるが，この報告では $\lambda\geqq1$ とする。

最大値付近の Q_y-x サイクルは大体図８に示す２種のパターンに分類できる[11]。パターンA は比較的降伏強度の大きい場合か又は小さい場合，パターンBは共振振幅付近の場合に相当するものと考えられるが，この報告では一律にパターンAで取扱う。

$$E_s=\frac{{Q_y}^2}{{\omega_0}^2}(\mu-0.5) \tag{25}$$

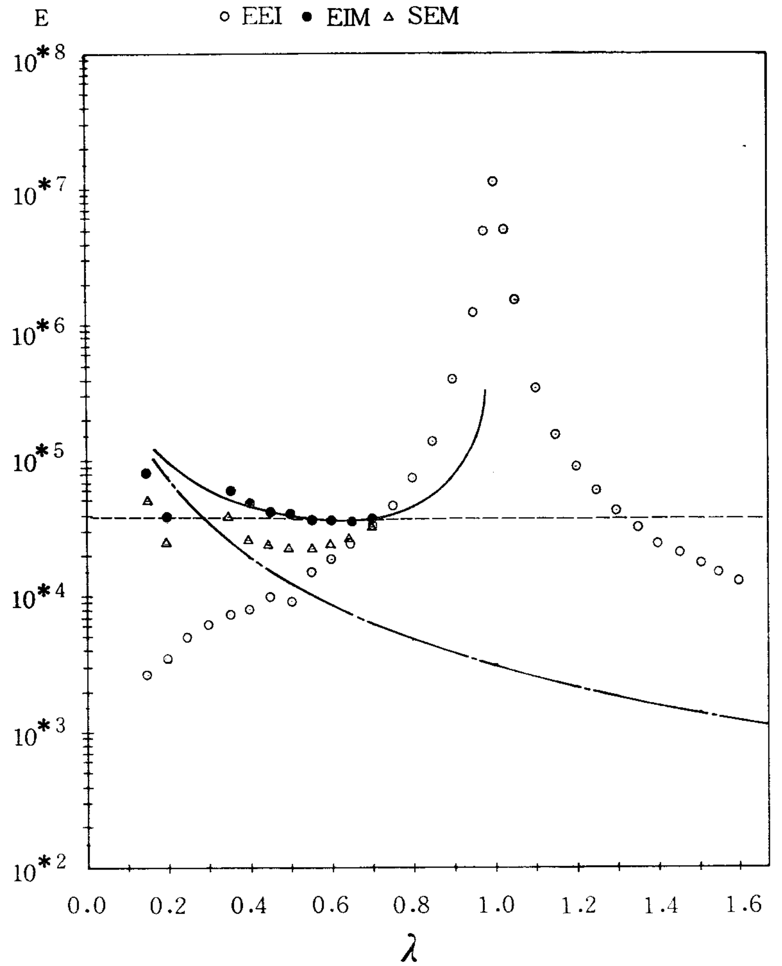
E
○ EEI ● EIM △ SEM
10*8
10*7
10*6
10*5
10*4
10*3
10*2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
λ

図　7

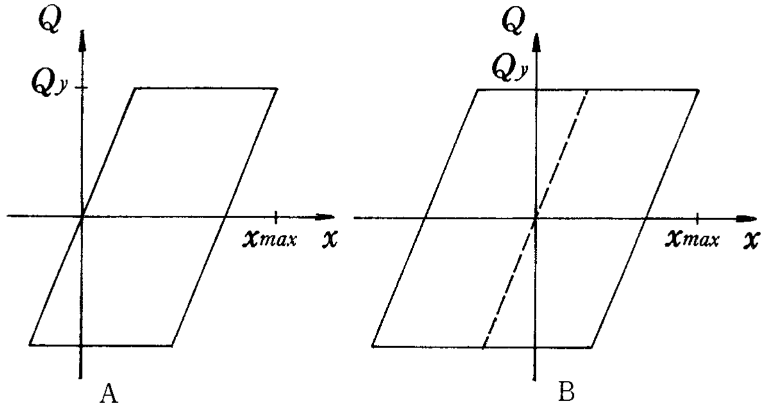
Q
Qy
xmax
x
A
Q
Qy
xmax
x
B

図 8　Q_y—x の 関 係

(25)式は共振点付近の系によって吸収されるエネルギーを過小評価することになるので *EIM* を修正する必要がある。図7の *SEM* は数値計算結果による共振点の E_s を示す。この報告では *EIM* の修正値として λ とは無関係に *EIM* の最小値を仮定する。D.E. Hudson の研究結果[12] によれば，弾塑性履歴による等価減衰定数 h は次式で与えられる。

$$h=\frac{2}{\pi}\frac{\mu-1}{\mu^2} \tag{26}$$

図9は h と μ 及び μ と共振振動数の低下の関係を示す。h は $\mu=2.0$ で最大となり，そのとき $h\fallingdotseq 0.16$ である。これより，*EIM* は近似的に $\mu=2.0$ で最小になるものと考えられる。これは同様の関係が一般の地震動にも成り立つとすれば，*EIM* は $h=16\%$ の線型応答スペクトルから直ちに求めることができることを意味しているので重要であるが，詳細な説明は他の機会に譲る。*EIM* の修正値は，(14) 式と(24)式より求めることができる。

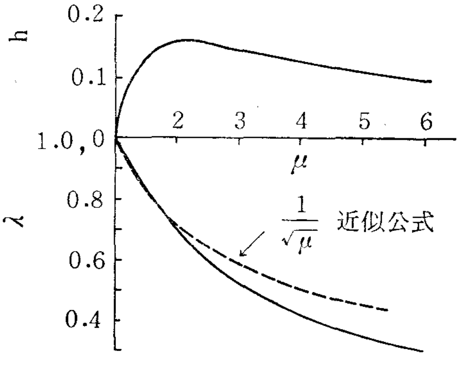

図9　h，λ—μ の関係
（田治見宏博士による）

共振振動数は近似的に次式で与えられる。

$$\lambda\fallingdotseq\frac{1}{\sqrt{\mu}} \tag{27}$$

(27)式より λ に対応する μ を求め，(14) 式に代入すれば近似的に Q_r を求めることができる。$Q_{e\cdot s}$ は次式で与えられる。

$$Q_{e\cdot s}=\frac{P}{|\lambda^2-1|} \tag{28}$$

$\lambda=0.8$ を除く以上の結果と数値計算結果の比較を図11に示す。$\lambda=0.8$ の場合は後述する。

5．2　弾塑性近似応答式の誘導

弾塑性近似応答式は入力エネルギー *EIO* と系による吸収エネルギー E_s を等置することで与えられる。$EIO=E_s$ より，

(1)　$\lambda<1.0$ の場合，

$$Q_y=\omega_0\sqrt{\frac{2EEI}{2\mu-1}}\quad,\quad 但し，\quad Q_{e\cdot s}\leqq Q_y \tag{29}$$

$$Q_y=\frac{\left(\dfrac{EIM-EEI}{Q_r-Q_{e\cdot s}}\right)\omega_0^2+\omega_0\sqrt{\left(\dfrac{EIM-EEI}{Q_r-Q_{e\cdot s}}\right)^2\omega_0^2+2\left(\dfrac{EEI\cdot Q_r-EIM\cdot Q_{e\cdot s}}{Q_r-Q_{e\cdot s}}\right)(2\mu-1)}}{(2\mu-1)}$$

但し，　$Q_r\leqq Q_y\leqq Q_{e\cdot s}$，$EEI<EIM$　　(30)

$$Q_y=\frac{\dfrac{EIM-E_0}{Q_r}\omega_0^2+\omega_0\sqrt{\left(\dfrac{EIM-E_0}{Q_r}\right)^2\omega_0^2+2E_0(2\mu-1)}}{(2\mu-1)}$$

但し，　$0<Q_y\leqq Q_r$　　(31)

$EIM\leqq EEI$ の場合，(17)式と(15)式の交点（図10参照）を $Q_{e\cdot s}$ と仮定する。これは，*EIM* が *EEI* 以下の場合，(30)式の平方根内が負になる可能性を修正したもので $\lambda=0.8$（図11-4参照）はこの場合に相当する例である。

(2)　$\lambda\geqq 1.0$ の場合，

$$Q_y=\frac{\frac{EEI-E_0}{Q_e}\,\omega_0{}^2+\omega_0\sqrt{\left(\frac{EEI-E_0}{Q_e}\right)^2\omega_0{}^2+2E_0(2\mu-1)}}{(2\mu-1)}$$

但し，　$0<Q_y$　(32)

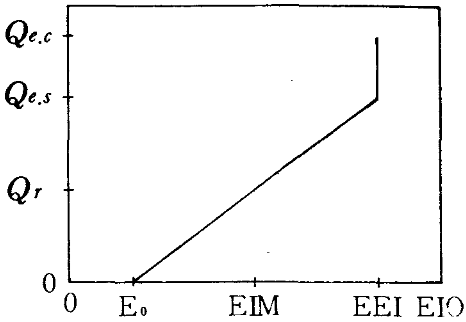

図10　Q_y—EIO の 関 係

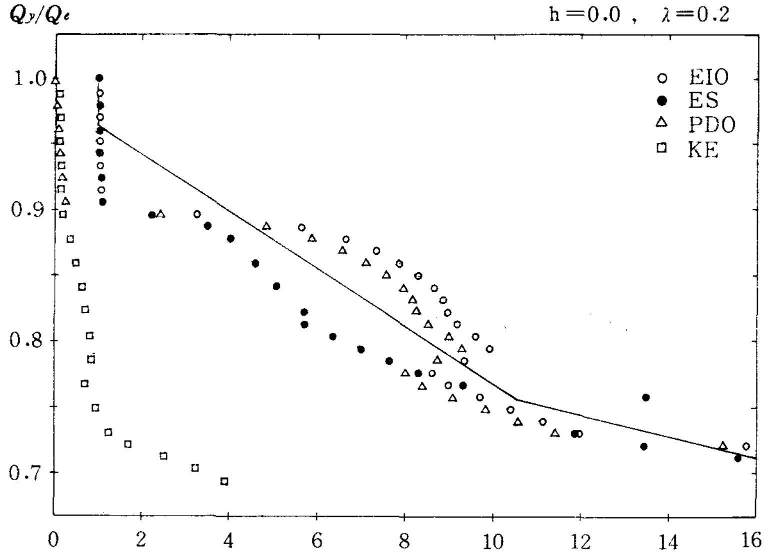

図11-1　Q_y/Q_e—E/EEI の 関 係

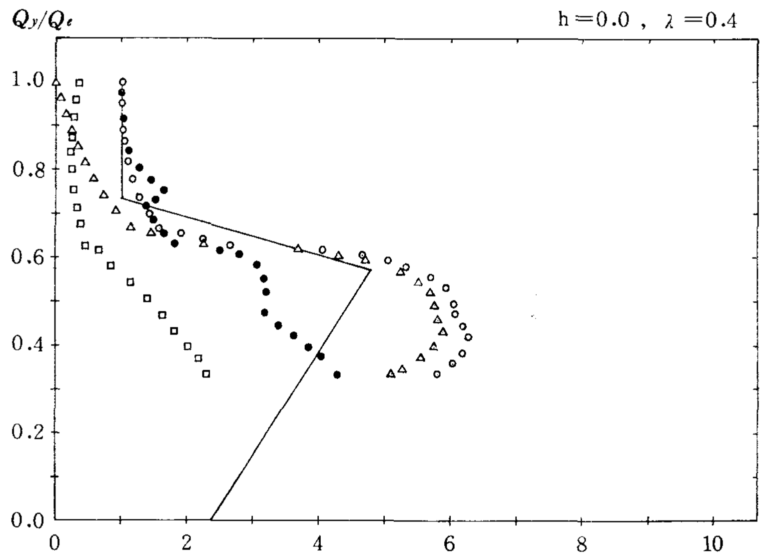

図11-2　Q_y/Q_e—E/EEI の 関 係

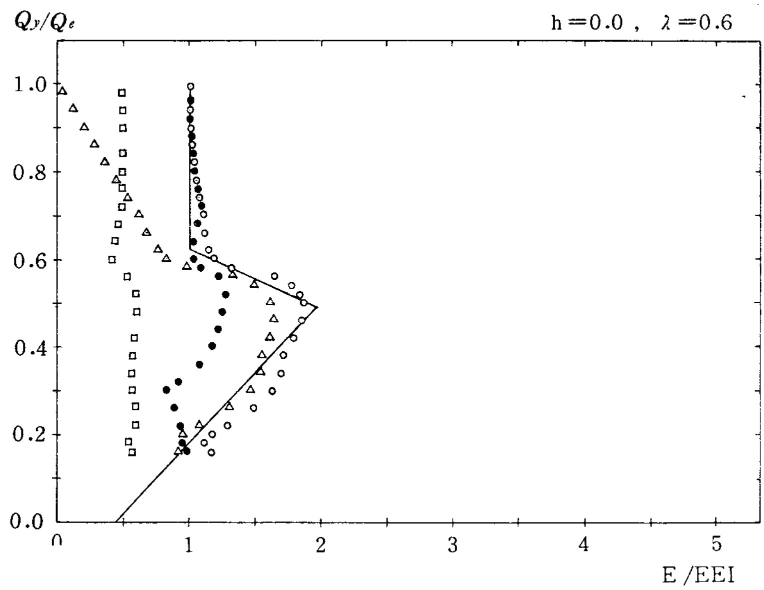

図11-3 Q_y/Q_e—E/EEI の 関 係

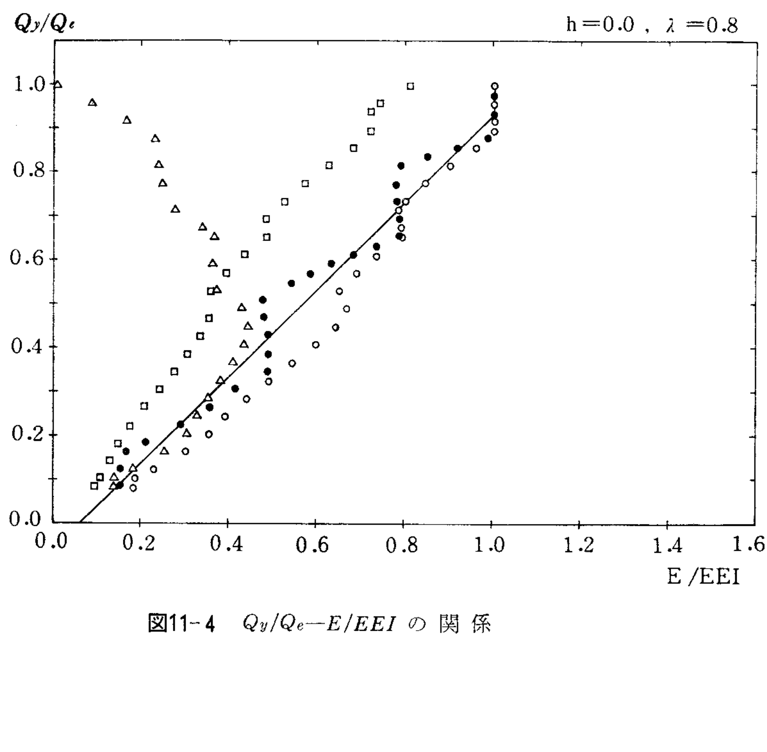

図11-4 Q_y/Q_e—E/EEI の 関 係

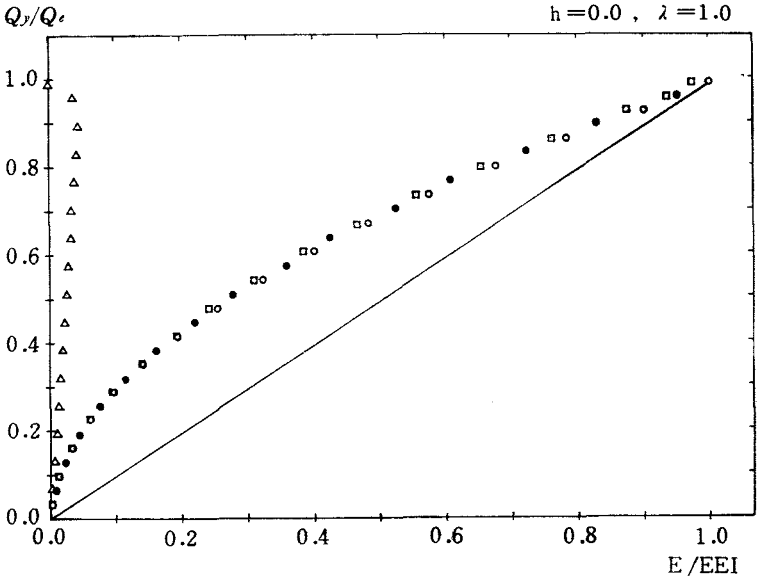

図11-5　Q_y/Q_e—E/EEI の 関 係

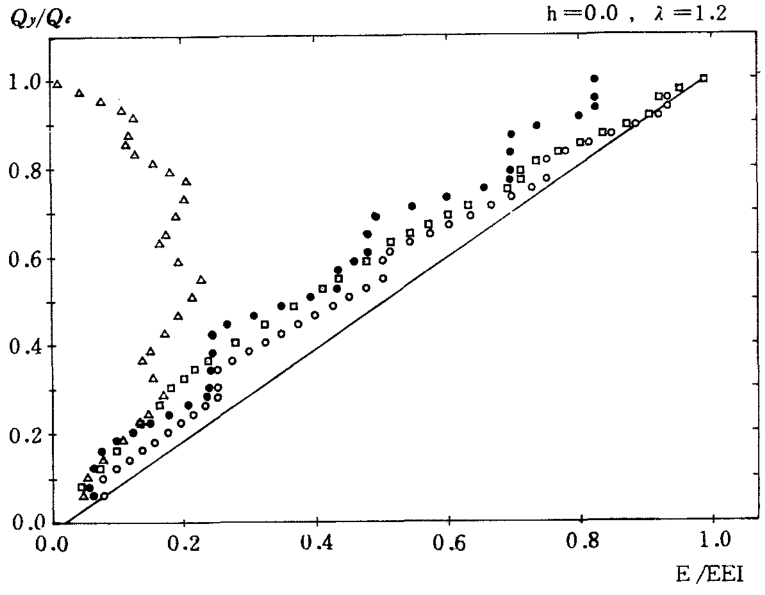

図11-6　Q_y/Q_e—E/EEI の 関 係

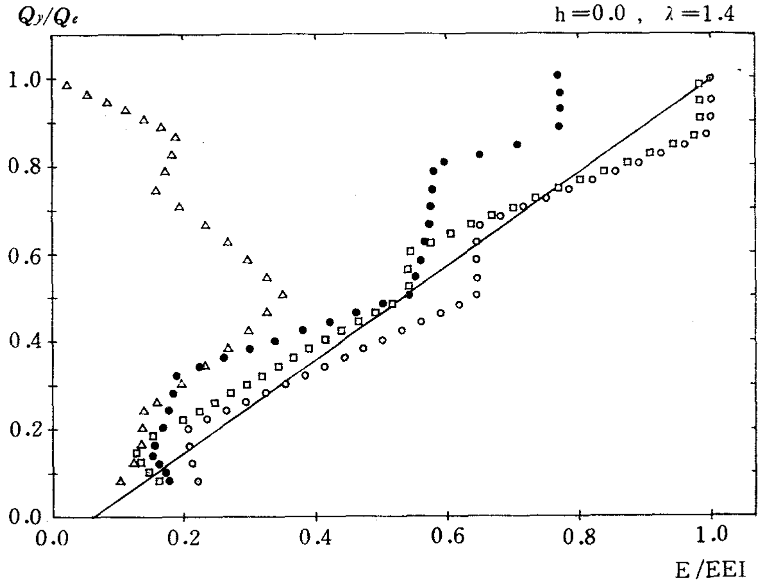

図11-7　Q_y/Q_e—E/EEI の関係

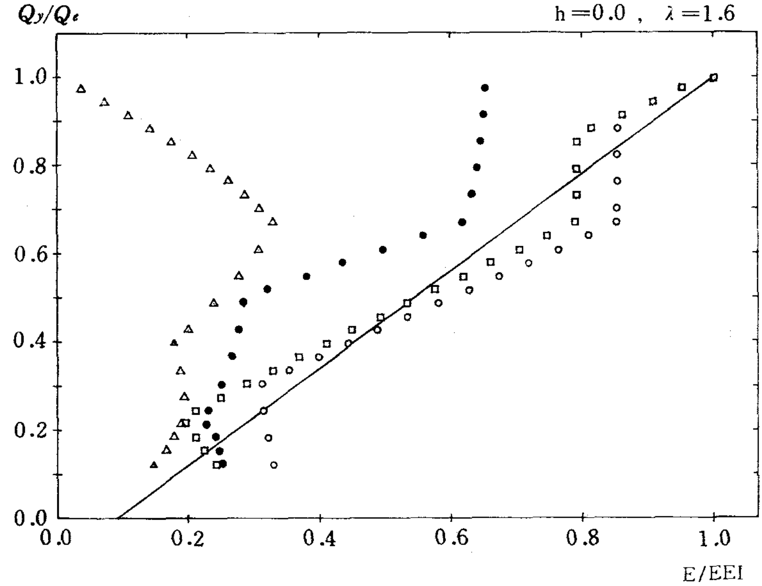

図11-8　Q_y/Q_e—E/EEI の関係

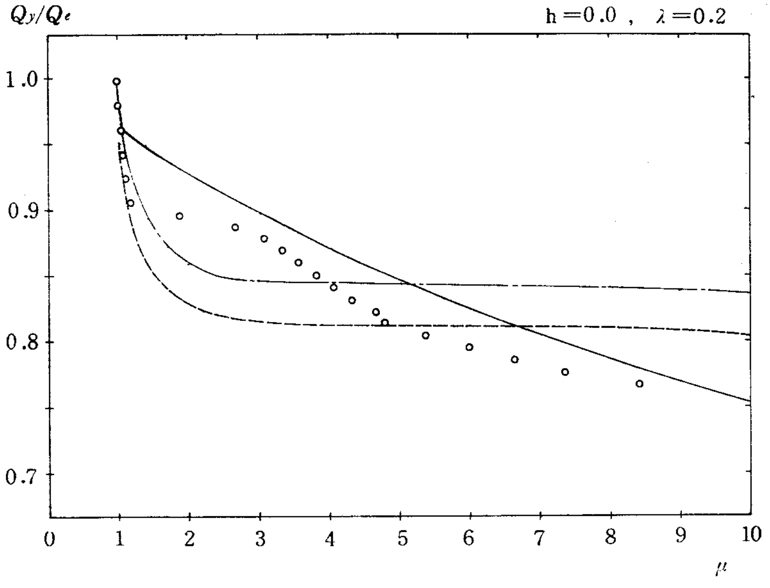

図12-1　Q_y/Q_e—μ の 関 係

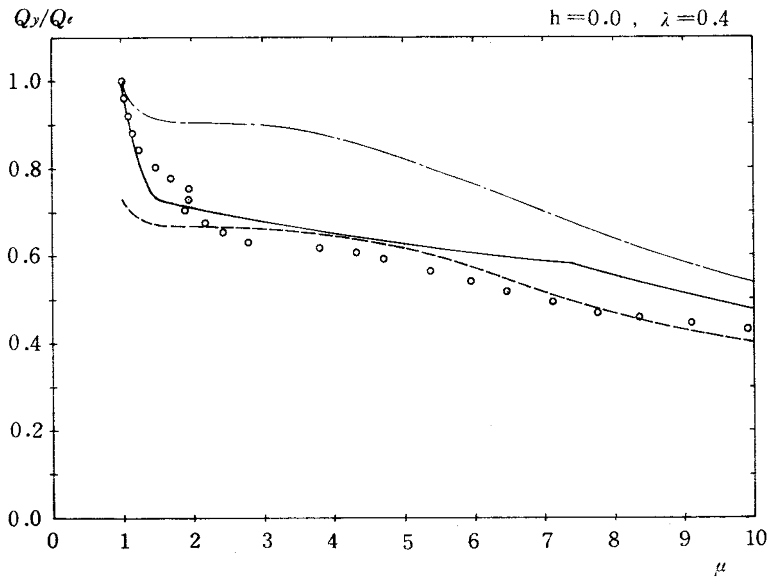

図12-2　Q_y/Q_e—μ の 関 係

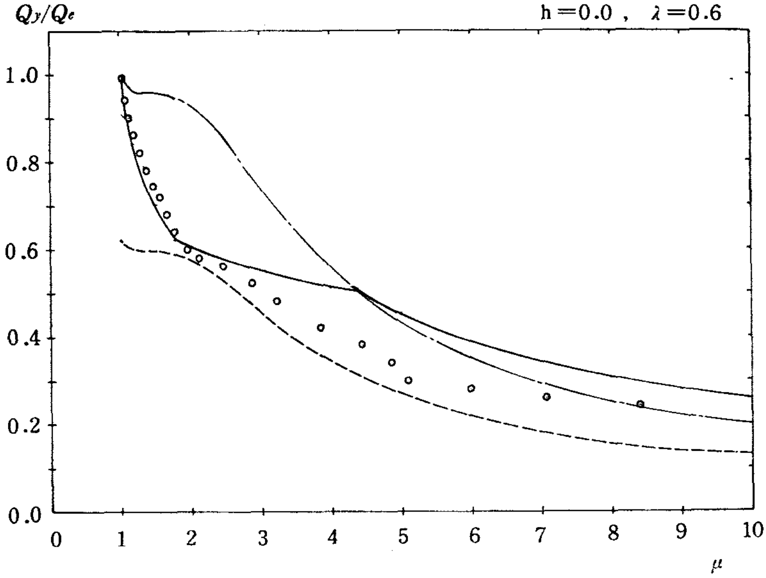

図12-3　Q_y/Q_e—μ の関係

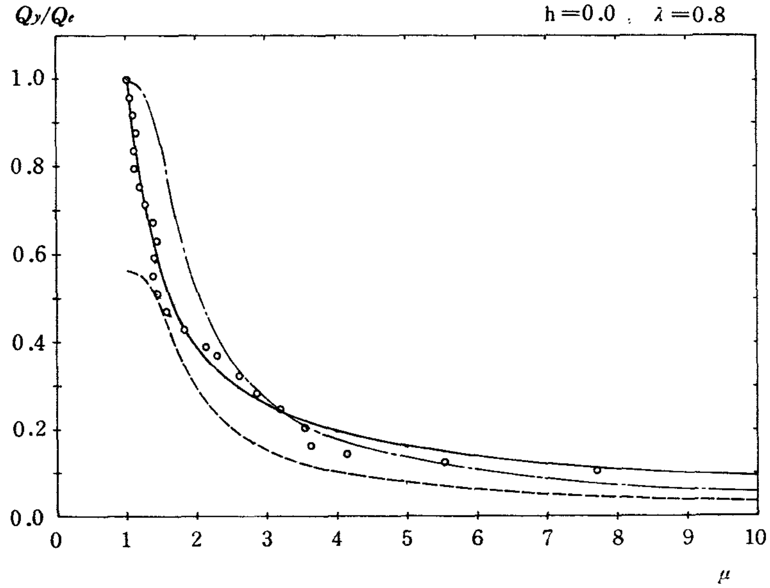

図12-4　Q_y/Q_e—μ の関係

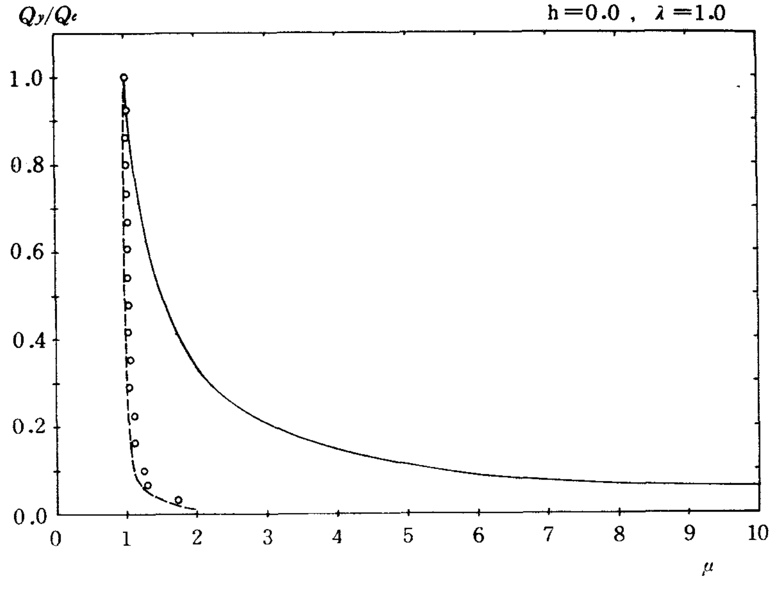

図12-5　Q_y/Q_e—μ の関係

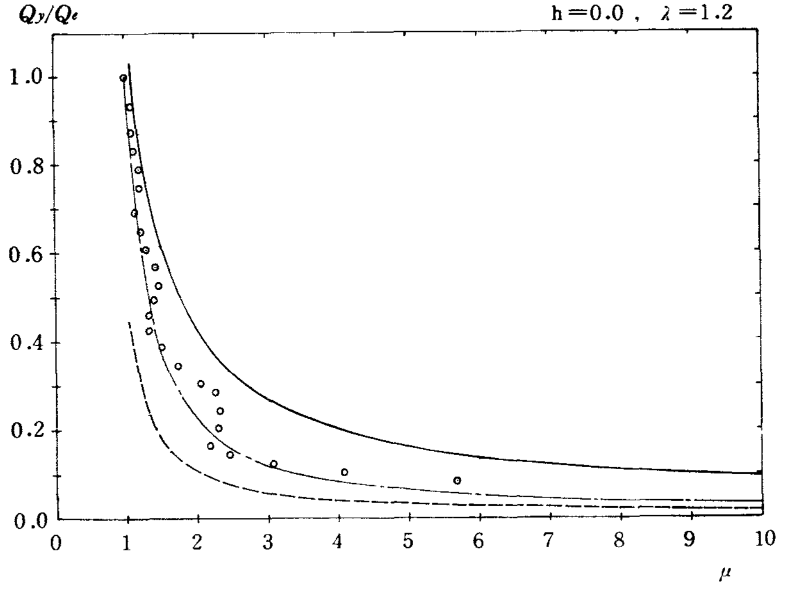

図12-6　Q_y/Q_e—μ の関係

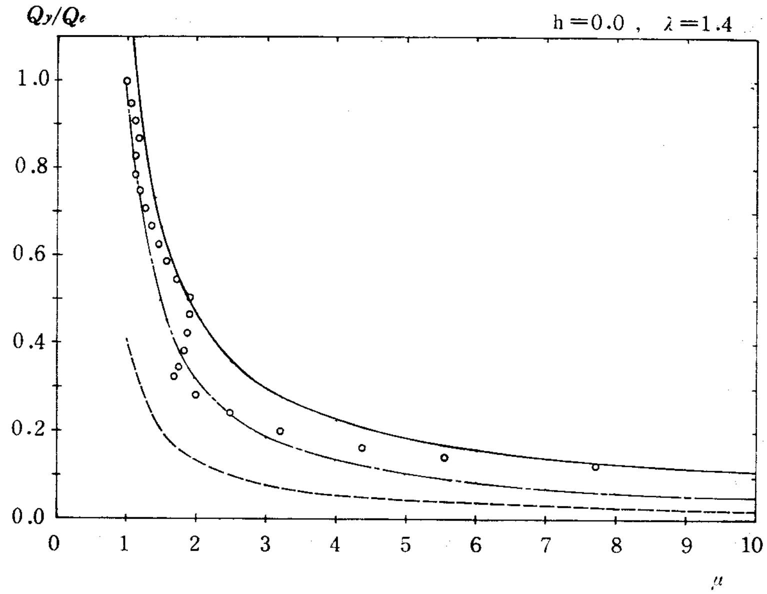

図12-7　　Q_y/Q_e—μ の関係

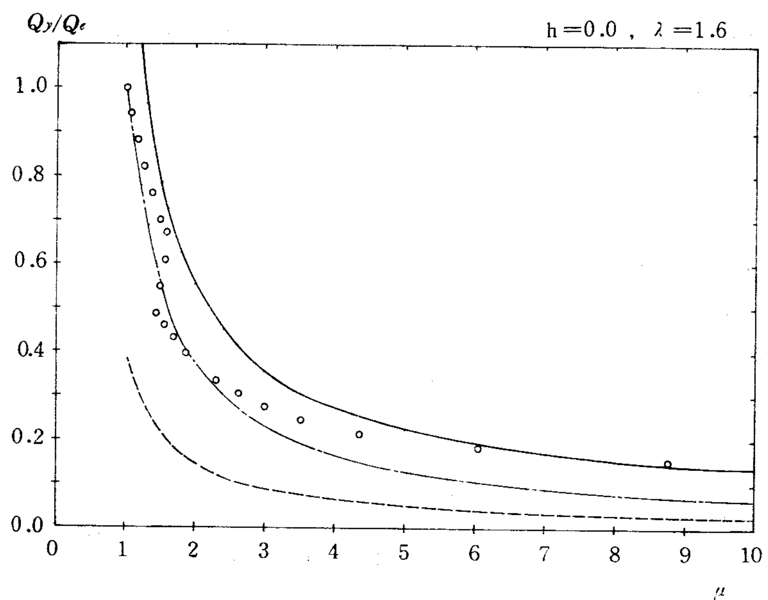

図12-8　　Q_y/Q_e—μ の関係

§6　解析結果とその検討

図12に(29)～(32)式で与えられる近似式と数値計算結果の比較を示す。$\lambda=1.0$の場合（図12-5参照）を除いて，近似式と数値計算結果は定性的にも定量的にもよく一致していると思われる。$\lambda=1.0$の場合，近似式と数値計算結果の差異は，近似式が *EIO* を過大評価したために生じたもので，近似式は数値計算結果に比較して最大変形を大きめに評価することになるが，近似式として十分耐え得るものと判断する。

§7　結　　論

降伏せん断力の変化による入力エネルギー特性と系によって吸収されるひずみエネルギーより，正弦波に対する完全弾塑性系の近似応答式について報告した。近似式は図から判断する限りかなり精度のよいものであり，一般の地震動への拡張が期待できるものと考えられる。

本報告の計算にあたり，呉工業高等専門学校計算機室 FACOM230—28S を使用した。関係諸氏に謝意を表わします。

参　考　文　献

1) 門前勝明：地震による構造物へのエネルギー入力と構造物のエネルギー吸収特性について．呉工業高等学校研究報告第12巻第２号，昭和52年３月
2) 門前勝明：正弦波地動による構造物へのエネルギー入力特性について．日本建築学会中国支部研究報告集，昭和52年３月
3) 門前勝明：減力時の剛性低下が地震応答性状に及ぼす影響について（その１，正弦波による応答解析）．日本建築学会中国支部研究報告，昭和51年３月
4) 加藤勉・秋山宏：強震による構造物へのエネルギー入力と構造物の損傷．日本建築学会論文報告集，第 235 号，昭和50年９月
5) 加藤勉・秋山宏：鋼構造剛接骨組の耐震極限設計．日本建築学会論文報告集，第237号，昭和50年11月
6) 加藤勉・秋山宏：鋼構造の弾塑性地震応答と耐震設計へのアプローチ．住友金属鋼構造研究特集号，第28巻第３号，昭和51年７月
7) 田治見宏：耐震塑性設計における過適震度を求めるための近似計算法．Proceeding of Japan National Symposium on Earthquake Engineering, 1962, Japan
8) T.K. Caughey : Sinusoidal Excitation of A System with Bilinear Hysteresis, Journal of Applied Mechanics, Trans. ASME, Vol. 27. Series E. 1960
9) 田治見宏：建築振動学．コロナ社
10) 門前勝明：減力時の剛性低下が地震応答性状に及ぼす影響（その１，正弦波による応答解析）．呉工業高等専門学校研究報告，第11巻第２号，昭和51年３月
11) 柴田明徳：１質点系の非線型応答の特性．日本建築学会関東支部第33回学術研究発表会，1963年１月
12) D.E. Hudson : Equivalent Viscus Friction for Hysteretic Systems with Earthquake-Like Excitations, Proceedings of the Third World Conference on Earthquake Engneering, 1964

（昭和52年５月31日受付）

昭和51年度本校教官による他誌発表論文

著　者　名	論　文　題　目	発表誌名または発表会名
佐藤　重夫 米倉　二郎 門田　博知 梅田　恵三	尾道市総合計画策定基礎調査報告書	中国地方総合調査会　昭和51年10月刊行
佐藤　重夫 曽根田　彰　他15名共著	広島都市圏における住宅・宅地の需給と適地に関する調査報告書	日本住宅公団関西支社　昭和51年10月刊行
下村　登	Mysticism in Steinbeck	第一回国際スタインベック会議(51.8) 福岡（九州大学）
兼本　富夫	経済生活の自由	憲法の知識（広島大学教授 畑 博行・中川 剛 編　有信堂）
原　茂樹（広大総合） 松尾　博（広大総合） 茶木　正吉	ゼフィラミンによる微量ウラン(VI)の吸光光度定量法	分析化学，25，644（1976）
灘野　宏正 寺内　喜男（広大工）	純粋すべり接触における摩擦面温度上昇（ストーカステック法による解析）	日本機械学会講演論文集（No. 768—2）
〃	平歯車のスコーリング評価式の検討	日本機械学会講演論文集（No. 768—3）
〃	軸交さ円筒試験機による円筒の凝着強さの研究（材料のかたさおよび試験温度の影響について）	広島大学工学部研究報告（第25巻，第1冊）
京免　進 近江　宗一（阪大工） 碓井　建夫（阪大工）	円管内乱流脈動流れの圧力・速度分布（摩擦速度の時間的変化を考慮した場合）	日本機械学会講演論文集（No. 760—5） （76—4，東京）
野村　利英 中前栄八郎（広大工） 山縣進一郎（中国電機製造K.K.） 松崎　誠（中国電機製造K.K.）	変圧器漏洩リアクタンスの計算法に対する一考察	電気学会全国大会講演論文集 （51年4月，東京）
広光清次郎　他	A Unified Study on the Output Probability Distribution of Arbitrary Linear Vibratory Systems with Arbitrary Random Excitation.	*Journal of Sound and Vibration.* 43, 4
〃	オンライン処理による代表的騒音統計量の新たな一推定法(理論と実験)	日本音響学会誌　32，3
〃	A Stochastic Study of the Nonstationary Non-Negative random Process Based on Two Models of Time Series : Multiplication and Addition.	*Journal of Sound and Vibration.* 45, 3
〃	非線形帰還型確率システムの多変量出力分布に関する一非定常応答解析	計測自動制御学会論文誌　12，4
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呉工業高等専門学校
研究報告

第13巻　第1号（1977）
（通巻　第20号）

昭和52年9月印刷
昭和52年9月発行

編集兼発行者　呉工業高等専門学校
〒737　呉市阿賀南2丁目2—11
電話呉（0823）71—9121

印刷所　柳盛社印刷所
〒730　広島市東白島8—23
電話（21）2148・2149

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OF THE
KURE TECHNICAL COLLEGE