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ON THE SAFETY OF STRUCTURES AGAINST EARTHQUAKES

BY

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For about thirty-five years since the well-known Tokyo earthquake in 1923, we have experienced a number of disastrous earthquakes occurred in several areas of Japan. The following table will show the dates and locations of these major earthquakes including the one taken place in Formosa.

Table 1.

1	Jan.	15,	1924	IZU-EARTHQUAKE	
2	May.	23,	1925	TAJIMA-	〃
3	Mar.	7,	1927	OKUTANGO-	〃
4	Sept.	21,	1935	TAICHU-	〃
5	May.	4,	1953	TOTTORI-	〃
6	Dec.	7,	1944	TOKAI-	〃
7	Jan.	13,	1945	MIKAWA-	〃
8	Dec.	21,	1946	NANKAI-	〃
9	June.	28,	1948	FUKUI-	〃

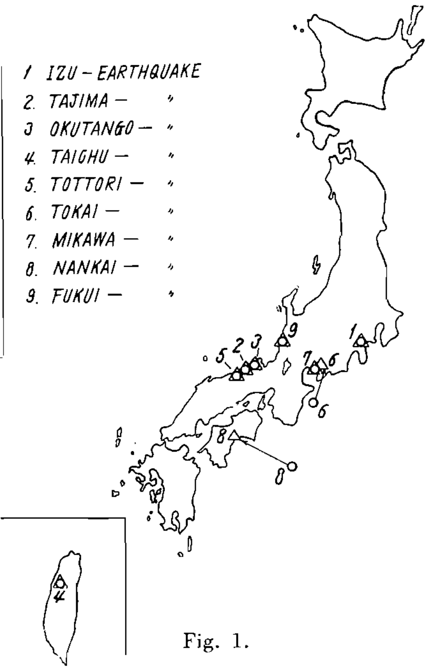

Fig. 1.

Except the first three earthquakes in Table 1 and Fig. 1, each time I was given an opportunity to inspect the structures in the damaged district and, with an exception of earthquake No. 7, the Mikawa earthquake, I have observed that in the most affected area almost all the houses were completely destroyed. Basing on a series of my experience together with the results of inspections, I shall pick up some topics which seem to be important to seismic engineering.

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1) Presented at the Meeting of Studies on Seismic Engineering, held in Messina, Italy, from 10th to 13th December, 1959.

2) Director of Disaster Prevention Research Institute, Professor of Structural Engineering, Kyoto University, Kyoto, Japan.

Fist of all, the results of inspection of damages due to the Tottori earthquake are shown in Fig. 2, (1)[1], (6). From the seismograph records, it was supposed that the epicenter was in Shikano-cho, located at about 14 kilometers south-west of Tottori city where most of the damages were reported. The contour map in Fig. 2 illustrates the percentage of damages, from which we can point out a distinct fact that an area of very little damage was found to be only 2 kilometers apart from the locations where nearly 90% of houses were destroyed. This would indicate that the damage due to an earthquake is not associated with the distance from the epicenter.

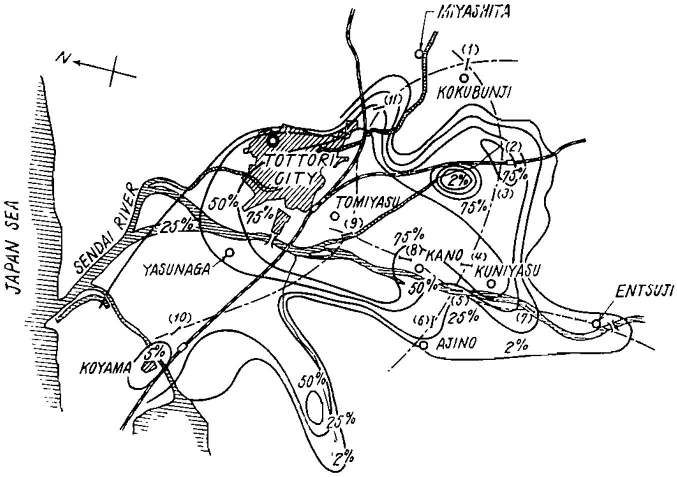

Fig. 2.

Seismologists, as well as earthquake engineers, in Japan have pointed out that the damage was distinct especially when structures were on an alluvium ground, but the above mentioned difference could be seen even at the points on the same alluvium field. Hence, the depth and softness of the alluvium layer would be considered as important factors associated to some extent with hazards due to earthquakes.

We began to study this problem by making a survey in Mikawa-area damaged in the event of Tokai earthquake in 1944 (2). The epicenter was regarded to be in the ocean and at about 20 kilometers south-southeast off Shima Peninsula. Local damages were reported in Mie-, Aichi-, and Shizu-

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[1] Numbers in parentheses refer to the Reference at the end of the paper.

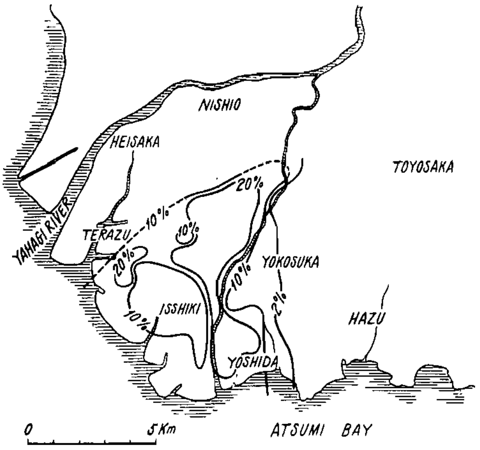


Fig. 3.

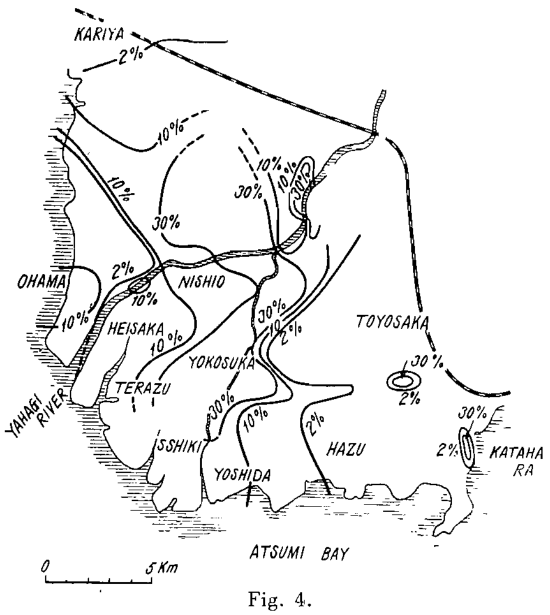


Fig. 4.

oka-Prefectures (Figs. 3, 4 and 5) (3).

A historical survey tells us that earthquakes with the epicenter at that spot would occur every hundred years or so, and accompany local tidal waves over a broad area in the western part of Japan. It is, of course, needless to say that earthquake shows each particular feature every time. On the contrary, however, it can be assumed that similar earthquakes would cause a similar extent of hazards and, therefore, that a comprehensive study of damage due to an earthquake in the past will be able to forecast possible damage caused by another similar earthquake in the future.

Thus, the procedures we have taken so as to study the relationship between the grade of damage and the property of the ground in the damaged area in the event of Tokai earthquake were first to draw a contour map for damaged structures and then to carry out a survey on the softness and depth of strata under the ground by measuring the velocities of elastic waves generated from dynamite explosions. While this sort of artificial earthquakes were being commonly used for seeking of petroleum in the United States and other countries, we have applied this method to a new purpose, namely, the investigation of the property of ground in the area where a great deal of damages due to earthquakes were observed.

Coincidence of the degree of damage with the depth estimated from our artificial earthquakes was found to be remarkable, as it is shown in Fig. 6, (2), and it has not only supported the established theory, "the more distinct damage is seen as the thickness of the soft layer is larger", but also suggested the importance of the survey on the thickness and softness of the ground in order to anticipate possible damages in that area.

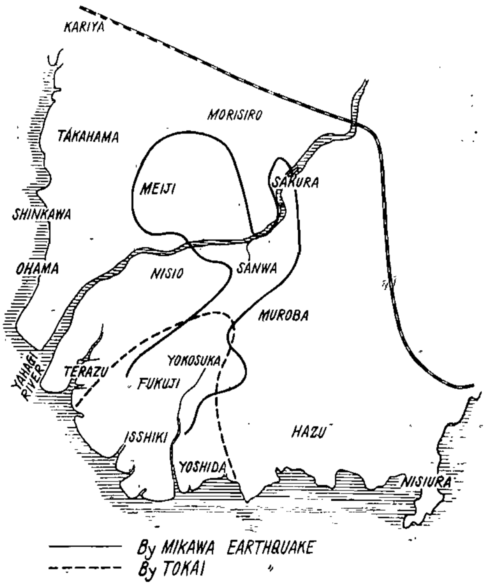
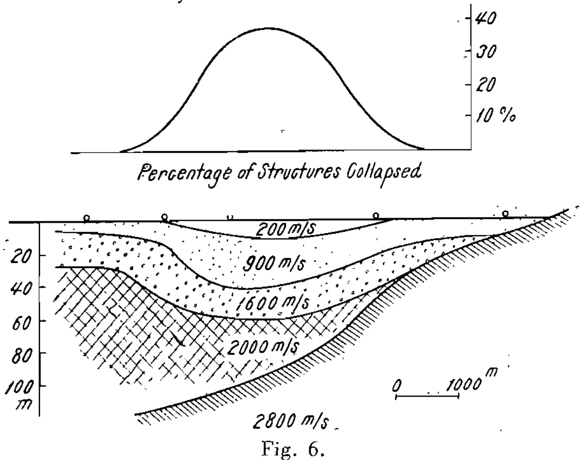


Fig. 5.



Percentage of Structures Collapsed

Fig. 6.

The investigations by this method have been carried out for the areas of Mikawa, Tokai, and Tottori. From the survey at Tottori, a new fact was noticed (4). It was that among the areas where the ground is covered by a soft alluvium layer of almost the same thickness and the soil has the similar velocity of longitudinal wave, V_P, there was an area of very few damages reported. While the area with a remarkable damage was on an aged alluvium layer as this area is called "Kokubunji" which sounds like that a temple was dedicated here in the eighth century. This alluvium layer is supposed to contain a smaller amount of water, and it was made clear that velocities of the transverse, as well as surface, waves, V_L, in this layer were far different from those in other alluvium layers, whereas the velocity of the primary wave, V_P, were almost the same. Namely, the velocity V_L in this layer was larger than the other, so that the duration of the wave was shorter.

Therefore, as criteria on the grade of damage for various areas, we have chosen the depth of soft layer and the values of V_L as well as V_P, which are both concerned with the property of elasticity of the ground. Results of the investigations by the artifical earthquakes enabled us to make contour maps of probable earthquake damage in the future for big cities as Kyoto, Osaka, Nagoya and so forth (5).

Whether or not these maps will tell the truth can not be made clear until a destructive earthquake will occur in those areas. Nevertheless, I would like to believe these are not entirely out of focus, but these maps will be useful for city-planning to locate important public buildings.

Investigations to portray clearly the difference of earthquake motions due to the difference of the property of ground have been aimed and carried out at the Earthquake Research Institute, Tokyo University, since late Dr. Ishimoto was the director. And, it has been concluded that a specific frequency of the seismic waves was found to predominate, depending upon the property of the ground.

Recent investigations also show that large displacements of earthquakes are recorded on a soft ground. Then, a question may come up : Why a great deal of damage results on the soft ground? It may be considered that the extent of damage to wooden Japanese houses are intimately associated with the displacement of the ground motion. However, we are not sure that, if the mechanical properties of the ground vary for several adjacent areas, distinct difference will be observed in the velocity or acceleration of ground motion in the event of an earthquake. If we can make it clear that either velocity or acceleration of the ground motion does not relate to the properties of ground, it must be easier to find an answer to the question: Is the structural damage associated with the mechanical properties not only of structures but also of the ground? That is to say, if the value of the velocity of ground motion is not affected by the mechanical property of ground, we could explain that damage to rigid masonry structures would be larger if they were on a hard ground, while flexible wooden Japanese houses will be terribly damaged on a soft foundation. For the soft ground, a longer period of earthquake motion is generally observed, and visa versa. Hence, if we assume that the velocity of ground motion is the same for grounds of different stiffness, a large value of acceleration is to be found even when the displacement of the hard ground is small.

Why damage reaches to a great extent on a soft ground? And where the theoretical evidence lies? It has been believed that the damage is caused by the transverse wave in earthquakes. As to the behavior of propagation of the transverse wave, however, there is not any reason why the amplitude of the wave develops so apparently on the soft ground. Only when there exists a definite relationship between the speed of the wave and the depth of the soft layer, it has been proved theoretically that the transverse wave is predominant because of resonance. However, this fact doesn't seem to be enough to illustrate the whole aspect of the relationship between the property of ground and the damage to structures. A large ground displacement also results from the surface waves travelling through the soft layer. But, up to now, the surface waves were regarded as to have nothing to do with damage to structures. Consequently, here is the point which we would like to learn from the seismologists who are interested in the analysis on the propagation of seismic waves.

Also, we wish to know what sort of waves have actually been observed on a soft ground, and how they were different from those observed on a hard ground. Theoretical approaches will, of course, be indispensable so as to solve the fundamental problems whether or not the results from observations of small size earthquake would be applicable to telling the features in the event of major earthquakes.

We have mentioned here that a large extent of damage has been seen on a soft ground and that we have a means of quantitative estimation of the damage for different sorts of ground layers. On the other hand, it is nevertheless an undeniable paradox that there were some earthquakes in which the damage to structures has nothing to do with the property of ground.

In early days, late Dr. Torahiko Terada, a member of Earthquake Research Institute of Tokyo University, pointed out this fact after he made a survey on the Zenkoji earthquake which had repeatedly occurred in the neighborhood of Zenkoji in the mountainous area of central Japan (7). Also, the results of our own observation at the Mikawa earthquake, cited as No. 7 in Table 1, have shown the above features. The Mikawa earthquake, being supposed to be an aftershock of the Tokai earthquake, again destroyed almost the same damaged districts as shown in Fig. 3. Then, it was noticed that remarkable damage has not been found in the area of alluvium layer but in the district of presumably harder, diluvium ground. The distinct fact, therefore, leads us to recognize that in some earthquake the damage may be resulted to some extent regardless of the property of the ground and that it may not be alleviated even on a diluvium.

From what I have spoken already, we may draw a hypothesis here that these features are inherent to the earthquakes whose origins are located near and not so far below the ground surface. This has, of course, to be assured by future observations of earthquakes. Even while it is true that in the events of some earthquakes damages have resulted regardless of the property of ground at several districts, it has been known so far that these were only local, small-size earthquakes. As to major earthquakes occurred in Japan, effect of the property of ground on the damage has been appreciable. Thus, we have to emphasize the significance of investigations concerning to the problem.

Correlations between the soft ground and damage should be considered together with the mechanical property of the Japanese style buildings. And, further discussions on the property of structures and its relationship with earthquake damage will be given later.

While the mechanical property of the ground is intimately related to the grade of building damage, the mechanical property of structures is much more concerned with it. It is almost unfeasible to improve the property of ground by any means, but the mechanical characteristics of structures are the ones which can be designed. For this, the merit of earthquake engineering should be recognized.

I would like to show here some empirical data so as to mention about a problem of structural materials which are of concern with earthquake-resistance of structures.

Table 2.

		Number of Structures	Not damaged or slightly damaged	Seriously damaged	Half collapsed	Collapsed
Steel Structures	Steel-skeleton with reinforced concrete facing	12	12 100%	0 0%	0 0%	0 0%
	Steel-skeleton with light facing	35	33 99.3%	2 5.7%	0 0%	0 0%
	Total	47	45 95.7%	2 4.3%	0 0%	0 0%
Reinforced Concrete Buildings	Factories	60	50 83.3%	3 5.0%	4 6.7%	3 5.0%
	Office Bldgs	165	154 93.3%	8 3.6%	2 1.2%	1 0.6%
	Shops	62	54 87.1%	6 9.7%	0 9 %	2 3.2%
	Dwelling Houses	52	47 90.4%	4 7.7%	0 0 %	1 1.9%
	Schools	21	20 96.3%	1 4.7%	0 0 %	0 0 %
	Storages	124	106 85.5%	15 12.1%	3 2.4%	0 0 %
	Auditroriums	5	4 80.0%	0 0 %	1 20.0%	0 0 %
	Pubic Blds	19	18 94.7%	0 0 %	1 5.3%	0 0 %
	Others	75	66 90.4%	5 5.8%	2 2.8%	0 0 %
	Total	581	519 89.4%	42 7.2%	13 2.2%	7 1.2%
Wooden Houses	Unburned Area	146248	140840 96.3%	2434 1.7%	1487 1.0%	1487 1.0%
	Burned Area	179983	149589 83.0%	7746 4.3%	11080 6.2%	11568 6.5%
	Total	326231	290429 89.0%	10180 3.1%	12567 3.9%	13055 4.0%
Stone Masonry Buildings	Unburned Area	442	279 63.1%	62 14.0%	45 10.2%	56 12.7%
Brick Buildings	Unburned Area	1673	1023 61.1%	282 16.9%	146 8.7%	222 13.3%

Table 2 shows percentages of damage to structure of various materials, resulted in the event of Tokyo earthquake in 1923. All the structures had been constructed before the building codes were enacted in Japan to specify earthquake-proof design. This table indicates that the damage to steel structures was little, and the percentages of damage to timber structures and reinforced concrete constructions were almost the same, whereas brick or stone buildings were mostly damaged.

In the event of Taichu earthquake in Formosa, it was observed that about 90% of traditional Chinese style buildings with brick walls or sun-burnt brick walls were destroyed at some districts, while damage of wooden houses in Japanese style was only ten percent.

This observation has given to us a confidence that it will be possible to lessen the extent of earthquake damages to structure even though we can not suppress the outbreak of earthquakes.

Now, to explain the reason why the variation of the grade of damage was found for structures with different materials, I am going to speak of the fundamental problem of characteristics of seismic waves and the mechanical property of structures, namely, what kind of elements or factors in the mechanical property of building materials are significant for the safety of structures against these seismic actions.

The seismograph records for an earthquake generally show a very complicated pattern, which is not simple like a sinusoidal wave but looks as if many waves of various periods are superimposed. We can see that a pattern of seismic waves in the acceleration-time record shows a period which is far shorter than that measured from the displacement-time record. This would mean that the seismic waves are superposition of a large displacement wave with a longer period ranging from 0.2 sec. to 1.0 sec. and a small displacement wave with a shorter period and, therefore, with a large value of acceleration.

Also, it may very well be known that ordinary building structures have natural periods of vibration in a range from 0.2 sec. to 1.0 sec. Therefore, unless future investigations will furnish us more sufficient information on the correlation between the property of ground and the action of seismic waves, it is hard to conclude that a building structure will not be excited by a ground motion which is resonant with the natural period of the structure.

It is now apparent that we have to analyse earthquake response of structures as a transient phenomenon but not a steady-state. A recent study of ours has drawn a conclusion, that is to say, when a simple system is subjected to an idealized earthquake represented by a full cycle of quadratic wave, the response of the system is mostly affected by the ground motion whose period, or duration, is resonant with the natural period of vibration of the system.

When the natural period of vibration of a structure is comparable with, and nearly equal to, the period of ground motion, the response of the structure is mostly associated with the magnitude of velocity of the ground motion. In 1935, I wrote a paper in which I have proposed that the effect of an earthquake on the response of structures is not related to its maximum value of acceleration but that the velocity of the ground motion is of much more significance as criteria relating to the intensity of the earthquake (8), (9).

Earthquake-resistant design of structures has generally been done by specifying that the structure in question will be able to withstand lateral loads of the magnitude determined as to be the weight of the structure times the ratio of the horizontal acceleration of earthquakes to that of gravity. Although such a straight forward method of computation, as a problem of statics, might be desirable at the final stage of structural design, I have to mention that the action of earthquakes can not be represented by a lateral force of certain magnitude determined by the seismic factor.

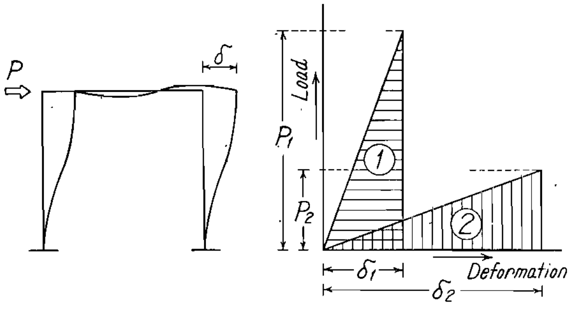


Fig. 7.

What I have discussed in may paper published in 1935 was that as the action of an earthquake we should consider the kinetic energy of ground motion, $^1/_2MV^2$, where M is the mass of a structure and V the velocity of the ground motion. Consequently, whether or not the structure would be safe against the earthquake depends upon the amount of the potential energy which will be stored in the structural members up to the collapse. Now, let us consider two simple frames of similar shape and size as shown in Fig. 7. These frames may have different magnitudes of deformation under the action of a lateral load P. And system (a) is supposed that it will collapse under the action of P_1 with a lateral deflection δ_1, while the second system, (b), will break down at P_2 with the corresponding lateral deflection δ_2. If the amounts of two potential energies stored up to the collapse are the same, namely, $^1/_2P_1\delta_1$ is equal to $^1/_2P_2\delta_2$, I would regard both of them have the same degree of earthquake resistance. The customary Japanese building codes, however, will give us a different answer which may most likely be unreasonable since the criteria involve only the values of P_1 and P_2. The result of the investigation carried out by the Joint Committee of the San Francisco, California Section; ASCE, and the Structural Engineers Association of Northern California has been found to check favorably with the conclusions of my paper of 1935 that the value of the seismic factor or the base shear coefficient has to be determined in accordance with the natural period of the structure in question, or, in other words, that different values of the seismic factor should be taken for structures with different periods of free vibration (10) (11).

We may consider two types of ground motions, one of which has a period, say, 0.2 sec. and the other 0.8 sec. If the maximum values of ground acceleration are the same, the displacement of the latter will reach 16 times as large as that of former whenever the similar pattern of the ground motion is assumed. Then, simply because of the acceleration value, can we regard these two types of ground motions as to have an identical intensity? Or should we consider that the earthquakes are of the same intensity if the maximum velocity of the ground motions are equal? I belive the latter question will meet the more reasonable evidences. More rigorously speaking, I would like to mention that the reasonable criterion or measure for the intensity of earthquakes should be the square of ground velocity which is proportional to the energy of seismic wave.

What I would like to have the reader's attention now is that, on the basis of the above montioned theory, damage due to an earthquake, say, A, will show a different aspect from that due to another earthquake, B, even if the Rossi-Forel intensity is the same for the both earthquakes. This would mean that if the period of ground motion, A, at the cycle in which the maximum mean velocity is attained differs from the corresponding period of ground motion, B, it will be resulted that a lot of damage would be expected in structures whose periods are close to either one of the periods of the ground motions. However, as far as we shall not be able to forecast the predominant period of ground motion at a district in the event of a possible destructive earthquake, the earthquake-resistant design for structures will necessarily be specified in such a more reasonable way that the potential energy being stored in the structure up to its collapse should be greater than $^1/_2MV^2$ for an assumed velocity of probable ground motions.

Of course, the responses of the two types of framed structures, as shown in Fig. 7, to the ground motions will be governed by the characteristics of the ground motions. The results of extensive investigations carried out since late Dr. Ishimoto at the Earthquake Research Institute, Tokyo University, have pointed out the general features that shorter periods of ground motions were observed on a harder ground and for the epicenters closer to the district (12). If we let two types of stiffnesses, No. 1 and

No. 2 in Fig. 7 represent a masonry structure and a timber building, respectively, the conclusions of late Dr. Ishimoto's investigations will be interpreted to mean that the rigid structures would be affected very much on a hard ground while flexible wooden buildings, especially in Japanese style, would have a great deal of damages if they are built on a soft ground. And this will be a good evidence to explain the relationship, that I have stated earlier, between the extent of damage to the wooden Japanese houses and the property of ground. This may also illustrate the reason of the peculiar example observed in the event of Mikawa earthquake. Since the epicenter of the earthquake was not so deep under the ground and located at a pretty short distance from the damaged district, the shock waves had a shorter period with a smaller amplitude though they were recorded on a relatively soft ground in the damaged area. Consequently, they were regarded to explain why many rigid structures on the diluvium ground were destroyed.

It will, therefore, be one of the important subjects in earthquake engineering to make clear what sort of structures or constructions will be most suitable to a ground of a certain property, from the viewpoint of earthquake-resistant design.

Now, I would like to explain that the ductility of structural materials is of great significance on the basis of earthquake resistance of a structure which may be evaluated in terms of the amount of potential energy stored up to the collapse of the structure. In Fig. 7 were compared the stiffnesses in two types of simple elastic systems. Similarly, the load-deflection diagrams for the other pair of systems would be as shown in Fig. 8, No. 1 and No. 2, in case if one of the systems is constructed with brittle materials and the other with ductile ones. Insomuch as the yielding load, P_1, is the same for both systems, it would be judged, from the static point of view, that the both systems would have an equal

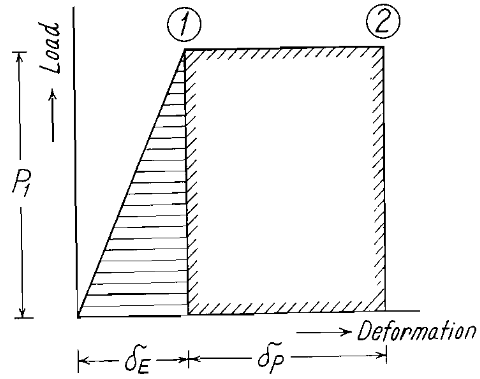


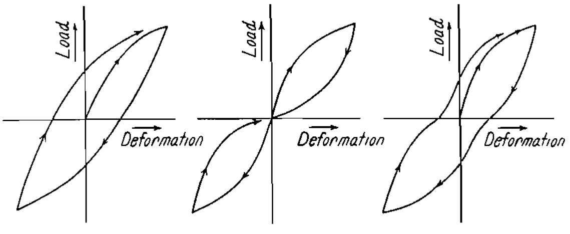
Fig. 8.

degree of earthquake-resistance, and, consequently, that the design value of base shear coefficient would have to be adopted for the systems even in case where the coefficient is prescribed in terms of the natural period of the structures. However, the real measure of earthquake-resistance of structures, namely, the potential energy criteria will show that the energies stored up to the collapse of these systems are $^1/_2P_1\delta_1$ for System 1, and $(^1/_2P_1\delta_1+P_1\delta_p)$ for System 2, respectively, and it is not seldom that the amount of the latter is several times as much as the former.

With this in mind, let us see Table 2, in which the grades of damages to structures in several types of construction. This table indicates that evidently brittle masonry structures were mostly damaged, being followed by timber, as well as reinforced concrete, structures which presumably have a little ductility, and that the damage to ductile, steel structures were the least.

Hence, in order to increase the earthquake-resistance of structures, the amount of potential energy would have to be made larger. This has been very well proved in the events of past earthquakes and this could be achieved in structural design if we carefully choose ductile materials and compose them into a ductile structure.

The elasto-plastic property of the structures characterized by the ductility of materials is also desirable for the safety of structures as it relates to the energy dissipations. The load-distortion characteristics for structures will generally show a specific shape of hystereris loops, which is inherent to the structural materials as well as to the pattern of loading. In Fig. 9, some patterns of hysteretic loops are shown (13).



(a) (b) (c)

Fig. 9.

This elasto-plastic property of soft spring type is interesting because the natural period of structures will be considerably prolonged when the elastic limit is exceeded during the vibration due to a large dynamic load, and, therefore, the system will hardly fall into resonance in a sense what the theory of linear, forced-oscillations illustrates. Moreover, the property will be effective for structures against the transient action of distinct ground motions of a small number of cycles. These problems were discussed in my paper presented to the First World Conference on Earthquake Engineering held at Berkeley, California, in 1956, (14), (15).

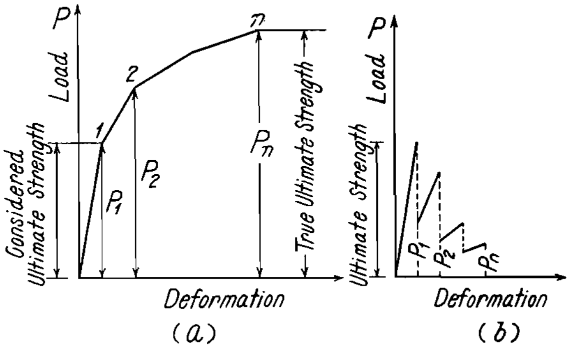


Fig. 10.

Composite, statically indeterminate, steel structures will show their load-distortion characteristics as shown in Fig. 10(a), as a structure with N redundant members will be collapsed after N plastic yieldings will take place at these redundant members if it is appropriately designed.

Therefore, for a repetitious loading, a large amount of energy dissipation will be expected until the collapse of the structure. On the other hand, if the structure is composed with a brittle material, a partial failure in one of the N redundant members will result the collapse of the structure as a whole. The load-distortion relationship may then be illustrated as shown in Fig. 10(b), (9).

Safety of structures against earthquakes will most satisfactorily be achieved by utilizing ductile materials which will enable the structures to withstand large plastic deformations. Two merits may be counted for this ; the first is a large amount of the potential energy stored up to the collapse, and, the second less possibility of resonance phenomena. It seems to me that an important aspect of the subject, nemely, the problem of deformation, has been neglected because of the prevalent way of thinking on the earthquake-resistant design, in which the action of ground motion is represented by a static force and the resistance of the structure is assumed to depend upon the strength but not the allowable deformations.

The deformation of structures depends, however, very much upon the composition of structural members even though the same ductile materials are utilized. Hence, it is not desirable to choose the type or composition of structures simply by specifying the strength against a static force. Much attention has to be paid on the deformation characteristics of structures, which is related to how to increase the total potential energy.

I have repeatedly mentioned that statically indeterminate structures composed with ductile materials such as steel may very well be favorable to the safety against earthquakes. The important subjects of study thereupon will be how and where should we choose possible locations of plastic yielding which will develop, step-by-step, in members until the collapse of the entire structure. It will also be significant to make sure that all of these local plastic deformation will be effectively kept or maintained up to the final stage.

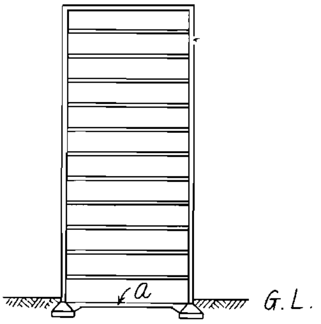


Fig. 11.

Concerning this field of research, related to the limit analysis of structures, I have published some papers so far, (9), (16), but I believe that the elasto-plastic behavior of building structures must be an indispensable subject of further research in earthquake engineering.

As to the locations of possible plastic yieldings, or plastic hinges in other terminology, it seems to me that it may be desirable if they develop in beams rather than columns, or that it will be much better if they will occur at joints of columns and beams. Moreover, if this situation would possibly be realized, to wit, if plastic hinges would firstly develop at both ends of the base girder, that is, member, (a), as shown in Fig. 12, the structure will now resemble to the one whose column bases are hinged to the ground. Member, (a), is a beam which is intended to fix the column bases so as to increase the statical rigidity of the structures. As a result of the plastic yielding in the beam at both ends, in the event of an earthquake, the period of vibration of the structure will be considerably increased, the magnitude of allowable deformation will be extended, and a great deal of earthquake energy is supposed to be dissipated into the structural members. On the basis of our investigations that I have been speaking of, these results seem to be very desirable for the safety of the structure against earthquakes.

Quantitative analysis on this problem is being carried out by my collaborators and myself (17) (18), and I hope we shall be able to present the result to the Second World Conference on Earthquake Engineering to be held in Tokyo and Kyoto, Japan, this summer.

From the point of view that I have mentioned, structural materials must be carefully selected and some suitable means of construction would have to be adopted in order to promote highly safety of structures against earthquakes. However, since no one can deny that architecture is greatly influenced by tradition, we shall have to reform it from the traditional means into much more desirable ones.

While it was noticed from many a survey that wooden Japanese houses have pretty high resistance to earthquakes, the construction generally has not so much stiffness for a lateral load, nor the restoring force, even though it is allowed to undergo a large amount of deformation. These might be said the weak points of the timber construction, which were disclosed in the events of past earthquakes, especially at locations of a soft ground.

It was, of course, reasonable that guidance has been oriented to make wooden Japanese houses be more rigid, but the most desirable device will be to construct the Japanese houses with steel.

Under those circumstances, light gage steel sections, made of cold-formed, thin steel plates, began to be produced in Japan several years ago, and have been being utilized for various types of building which otherwise had been constructed with timber.

The light gage steel construction would be one of the most fundamental approaches to lessen future earthquake damages to structures in Japan. This also reduces hazards of fire, so that this will enable us to minimize the earthquake damages for a century from today into less than one tenth of those in the past.

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AIJ-The Architectural Institute of Japan.

DPRI-Disaster Prevention Research Institute, Kyoto Univ.

JNCAM-Japan National Congress for Appl. Mech.

(E) Written in English

(J) Written in Japanese

(F) Written in French

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