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Earthquake Response Simulation by On-line Computer Test Control Method

Etude et contrôle du comportement sismique à l'aide de l'ordinateur

Simulation von Erdbebenreaktionen mit Hilfe einer On-line-Computer-Kontrolle

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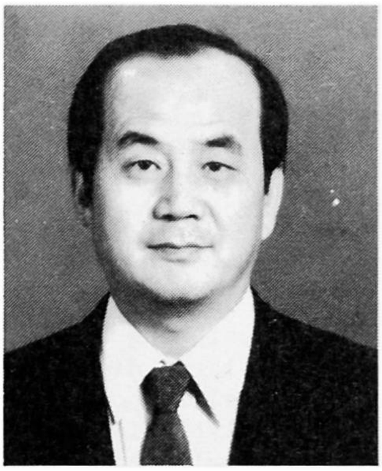

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SUMMARY
Analytical modelling of a structure is an important task in the seismic design procedure. Response calculation is so sensitive to the analytical model that formulation of the model must be carefully adjusted by simulation results. For this purpose the "on-line" computer test control method, which comprises computer analysis and experiment in a closed loop, is suitable.

RÉSUMÉ
Le modèle analytique d'une structure est un aspect important du processus de dimensionnement vis-à-vis des tremblements de terre. Les résultats des calculs de la réaction d'une structure sont très sensibles au modèle analytique, et la formulation du modèle doit être ajustée avec soin par des résultats de simulation. Pour cette raison, la méthode du contrôle des essais en ligne, incluant la simulation et l'expérience dans un cercle fermé, est appropriée.

ZUSAMMENFASSUNG
Die analytische Modellierung von Tragwerken ist eine wichtige Aufgabe für die Bemessung unter Berücksichtigung seismischer Beanspruchungen. Das Reaktionsverhalten dieser Modelle ist jedoch sehr empfindlich, so daß ihre Formulierung vorsichtig, anhand von Simulationsergebnissen, angepaßt werden muß. Zu diesem Zweck ist eine On-line-Computer Kontrolle angebracht, die in einem geschlossenen Kreis mittels eines Computers Daten von Experimenten erfaßt und gleichzeitig die Anpassung der analytischen Modelle durchführt.

1. INTRODUCTION

Research on the seismic performance of structural system against earthquake loading is being intensively conducted in the world, especially in the earthquake-prone countries. Much development of computers and their application techniques has exerted a great deal of influence on earthquake engineering. In designing structures, computer analysis to obtain the response behavior to earthquake ground motion consumes large amounts of time and effort since careful structure modeling must be carried out. Idealization of structures, equations to be solved, calculation methods suitable for the problems, analytical models such as the elastic-plastic characteristics of materials etc. are included. In addition, the exact values of physical constants are necessary before the execution of calculations. These values are usually obtained by experiments.

Highly developed computer techniques demand high quality of experiments. Fortunately testing techniques have also rapidly progressed. They are greatly owed to improved production techniques. In fact materials suitable for specific tests are now available, and can be manufactured to precise standards. Testing machine can be controlled in a precise manner, in most cases by computer.

Thus great advances have been made in both analytical and experimental fields. Both of them must be utilized in designing earthquake resistant structures. In behavior of structures, sometimes large discrepancies are found between idealized analytical solutions and actual response. Therefore, even in practical design procedure more realistic analytical models are required. These models depend on the accurate constitutive relations of materials, and more on correct formulations of elastic-plastic behavior of members and connections.

Loads or load effects acting on structures are determined by referring to statistical data on weights and meteorological phenomena. Seismic load, however, is exceptional. It cannot be determined independent of structural dynamic properties, because it is a load effect induced by the vibration of structures under earthquake excitation. The change of the dynamic properties due to yielding of members may alter the seismic load. It is difficult to determine analytical models by experimental results. In a strict sense the load applied to a test structure during test cannot be determined before execution of the experiment.

In order to overcome this dilemma, a new type of experimental technique was devised at Institute of Industrial Science, University of Tokyo[1],[2]. This technique is a combination of the numerical analysis and the experiment. It makes possible to trace the earthquake response of structural systems in the time domain without using a shaking table. It is called the on-line computer test control method, or the on-line test in abbreviation. In this presentation the basic concept of the on-line response test is described at first and then some test examples are highlighted in order to emphasize the importance of the on-line response test. Discussions are focussed on the accuracy of analytical models which are compared with the results of the on-line tests.

2. BRIEF DESCRIPTION OF ON-LINE COMPUTER TEST CONTROL METHOD

The basic concept of the on-line test is outlined in Fig.1. This technique is essentially a numerical analysis of spring-mass systems using the direct integration method. In the on-line test, however, the restoring force characteristics of the analyzed system are not postulated but are measured in a test carried out in parallel with the numerical integration. From this test, the earthquake response of the analyzed system can be obtained directly, and the tested structure itself undertakes the motion as if it were subjected to ground motion but at a slower speed. The on-line test is superior in several respects to the shaking table test, which is the most direct method for simulating the earthquake response of structural systems. The most significant advantage of the on-line test is that the loading of the on-line test can be quasistatic and can be halted at any time upon request, allowing close monitoring of detailed local behavior of the tested structure during earthquake response.

The on-line test has several advantages over other methods. Because the loading can be quasistatic(slow loading), less actuator capacity is required in the on-line test than in the shaking table test of the same specimen. In other words, large-scale or even full-scale test structures can be tested. Since the loading can be a repeated process of loading and pausing, conventional measuring devices used in quasistatic tests are sufficient in the on-line test, while shaking table tests must use simultaneous, continuous measuring. Finally, velocity adjustment loading in which the actuator ram velocity can be automatically controlled is possible when the restoring force properties of the test structures are affected by loading speed.

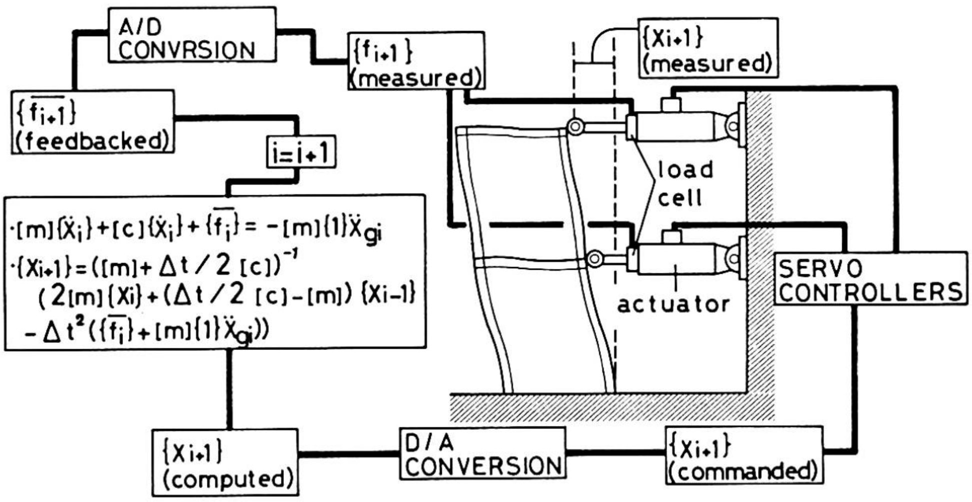


Fig.1 Block diagram of On-line test procedure

3.VERIFICATION OF ANALYTICAL MODELS

3.1 Importance of simulation

To emphasize the importance of verification of analytical models by simulation results, sensitiveness of calculation results to the model are examined in the case of the restoring force characteristics of a steel frame. A steel frame of three story and one bay bent is taken as an example. A 1/10 scaled model shown in Fig. 2 was tested by a shaking table to obtain the real characteristics of the restoring force of the first story [3]. The story shear force Q(the horizontal force induced at the level of columns' tops during excitation) versus the story displacement δ (the side-sway of the columns' top) relationship was obtained by the experimental model, as shown in Fig.3(a). An analytical model, namely, a mathematical expression describing the relation between the force and the displacement was formulated and then the hysteretic loops in Fig. 3(b) were produced with the mathematical expression according to the measured response displacement represented as the solid curve in Fig. 4. The two hysteretic loops is Figs. 3(a) and 3(b) are resembling each other from general appearances. The response displacement calculated by using the mathematical expression, however, is quite different as shown by the dushed curve in Fig. 4. This is a typical example to demonstrate how response calculation results are sensitive to the preciseness of analytical models used.

The adequateness of models used in response calculation must be examined by simulations.

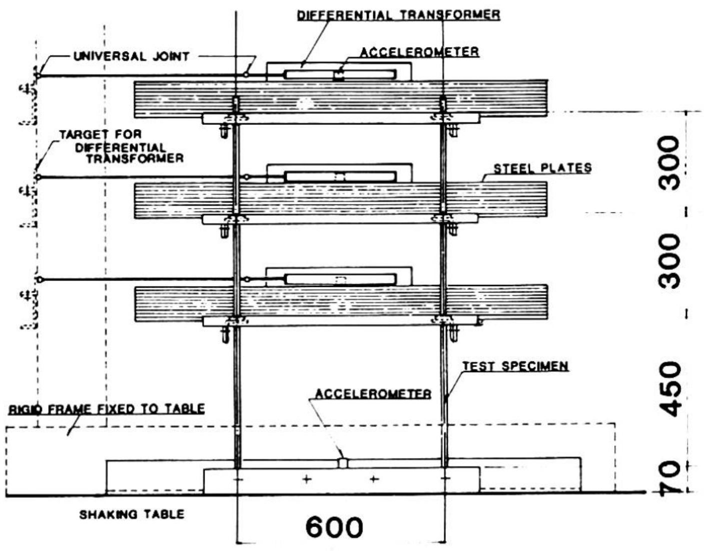
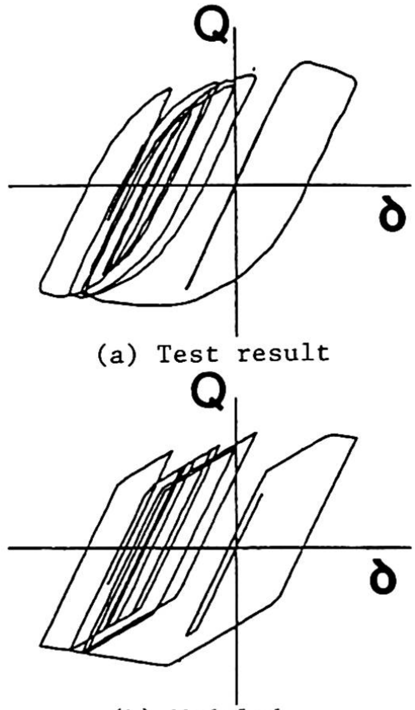


Fig.2 1/10 scaled model for shaking table tests



(a) Test result

(b) Modeled

Fig.3 Hysteretic loops

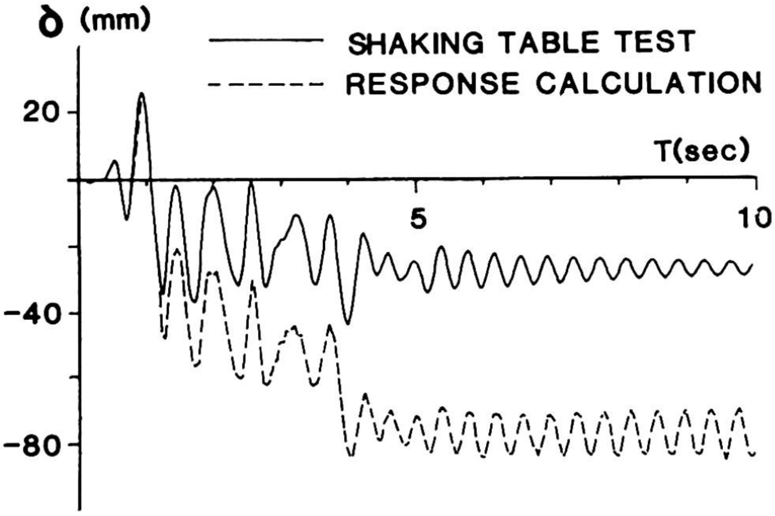


Fig.4 Response displacement measured and calculated

3.2 Earthquake response of a steel frame with high-strength bolt connections

High strength bolt connections are often used as in on-site erection work. The high-tension force provided by the high-strength bolts creates high-friction forces between connected plates, and therefore, the friction-type bolt connection is a very rigid one. The onset of yielding at the connection, however, causes a thickness reduction in the connected plates, which triggers slipping of the connected plates. After slipping the dynamic behavior becomes very complicated. A precise analytical model expressing such behavior is difficult to develop. Here, an analytical model was tried to be formulated upon cyclic test data that include the load at which the first slip occurs and the amount of slip rotation as well as the flexural rigidities. This model, called as Bolt Slip Model, postulates the hysteretic behavior of the beam with a bolt connection as shown in Fig. 5, though it is a rather simple expression being contrary to the real hysteretic loop. The adequateness of the analytical model was examined by comparing the calculation result with the simulation result obtained from the on-line test.

The on-line test was conducted on a frame with bolt connections [4]. The test frame is one-half of a two-story steel frame with high-strength bolt connections at the beam ends (Fig. 6) in lien of the frame as in Fig. 1 because of symmetry in deformation. From results obtained, the response displacement of the top of the frame is presented in a time history expression as the solid curve in Fig. 7. Meanwhile, the calculation result using Bolt Slip Model is shown as the dashed curve in the same figure. Agreement in both curves is satisfactory during dominant vibration. Hysteretic curves by the same on-line test is also shown in Fig. 8, in order to emphasize that the on-line test technique can simulate such a very complicate response behavior. It should be noted as one of the advantage of this test technique.

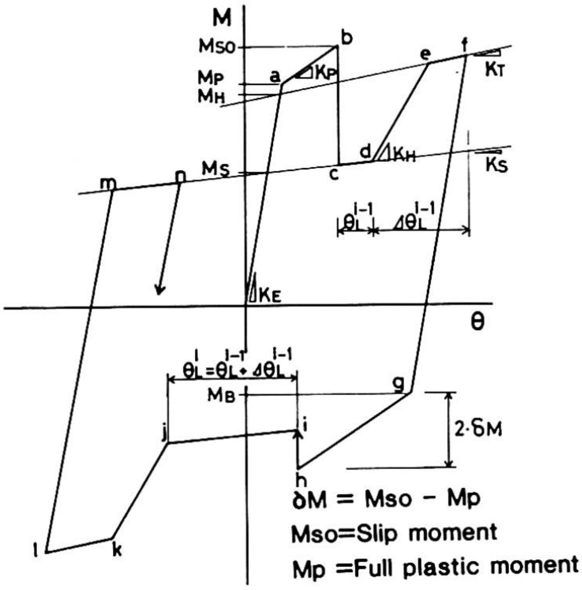


Fig.5 End moment M - end rotation θ of beam with bolt connection (BOLT SLIP MODEL)

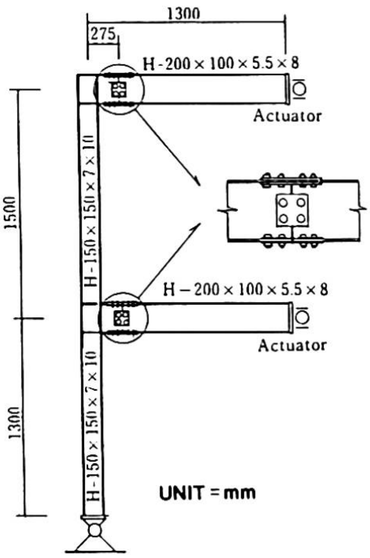


Fig.6 Test frame with bolt connections

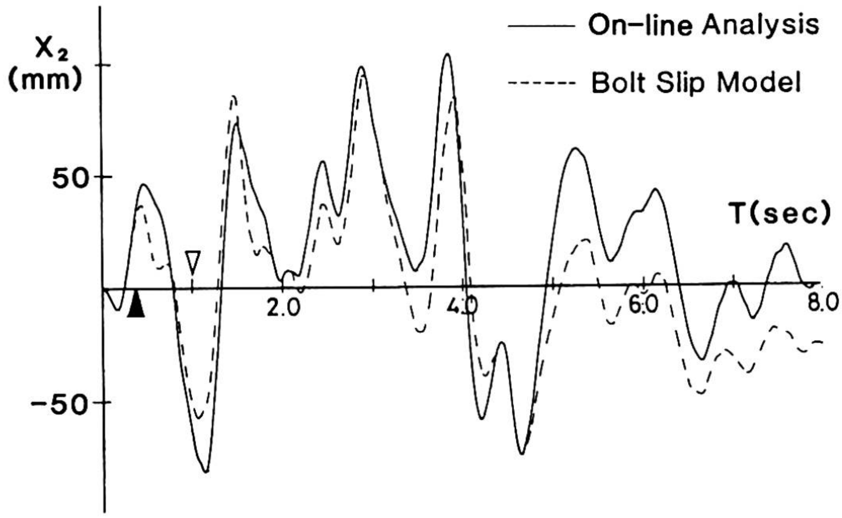


Fig.7 Response displacement simulated and calculated (Frame with bolt connections)

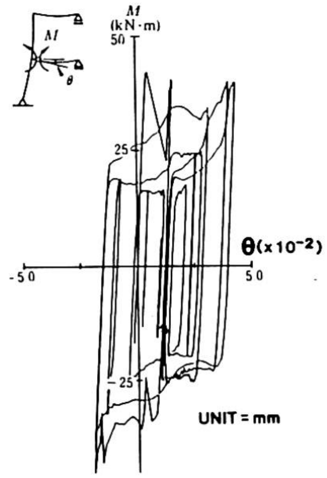


Fig.8 Moment-rotation relation by On-line test

In practical design procedure, a simple mathematical expression such as the bi-linear model as shown in Fig. 9 is often used. The preciseness of this model was also examined by the on-line test on a similar frame but without bolt connections. The response displacement of the top of the frame are compared with each other in Fig. 10. Agreement in these results is considered as being in the same degree as the previous case.

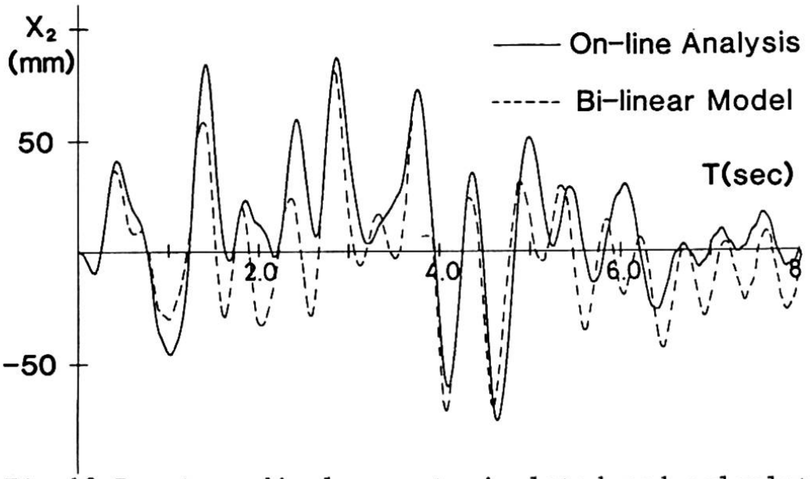


Fig.10 Response displacement simulated and calculated (Frame without bolt connection)

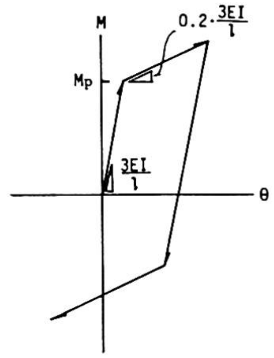


Fig.9 End moment M - end rotation θ relation of beam

4.CONCLUSION

For simulation of seismic behavior of structures, shaking table tests are often used. But these tests sometimes are not sufficient to predict real response behavior, because only small-scaled models of structures can be tested. The small-scale model tests are due to the limitation in capacity of a shaking table. It is not rare, however, that large-scale model tests, even full scale, are required to know precise response behavior of structures and structural elements. The on-line test described here is a suitable technique for such a purpose.

Modeling of structures is an important task in seismic design, but it is also difficult to achieve a satisfactory formulation which can describe real response in as easier way as possible. It needs a sort of compromise to be settled between preciseness and work. Analytical models must always be examined by the suitable simulation way. The raison is that damage sequence in disastrous stage of structures has never been recorded during earthquakes.

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