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Dynamic ultimate analysis of base-isolated system

J. Suhara, M. Takeda & T. Tamura
Shimizu Corporation, Tokyo, Japan

T. Mazda
Central Research Institute of Electric Power Industry, Abiko, Japan

K. Yoshikawa, Y. Takenaka & E. Tanaka
Kajima Corporation, Tokyo, Japan

ABSTRACT : The method which can evaluate the ultimate behavior of the base isolation system are proposed in order to establish the seismic safety margin analysis. The restoring force models of the isolation device are verified by comparing the analysis results with the experiment ones in the static force test. Next, the earthquake response analysis using the proposed models are performed. As the result, the effects of the properties of the isolation devices on the response are ascertained.

1 INTRODUCTION

In order to make sure of seismic safety on the base isolation system, it is important to establish the method of the earthquake response analysis technique not only in design level but also in ultimate states. To grasp the ultimate behavior of the base isolation system, it is necessary to evaluate the property of restoring force of base isolators at the large deformation.

The properties of the horizontal and vertical direction on the isolators are surveyed by the past experiment data(Mazda 1989,1991, Ishida 1991). The natural rubber bearing(NRB), the lead rubber bearing(LRB), and the high damping rubber bearing(HRB) which are the laminated rubber bearing with the fixed flange type are the subject of our investigation.

As the results, the properties of devices which should be considered in analysis models for ultimate states are found as follow, (1)the hysteretic loop of horizontal deformation in the hardening domain, (2)the dependence of the iterative deformation in the horizontal component, (3)the tensile hysteresis, (4)the dependence of the shearing deformation on the compressive stiffness.

It is known that the horizontal property of the device keeps the stable hysteretic loops at the low strain level, and the stiffness becomes smoothly hard at the large strain level. Because the restoring models which are ordinarily used in earthquake response analysis can not express this hardening of stiffness which is the typical property of isolator at the horizontal direction, two restoring force models are proposed. One is approximated by the multi-linear functions. In this model, parameters of model correspond to the physical constants, for example, the hardening stiffness, the yield displacement, and so on. Another is approximated by the smooth function. This model represents the restoring force curve of devices as really as possible.

The multi-linear model are examined by using the data of LRB and the smooth function model are examined by using the data of HRB. But, each model can be used for every type of devices if model parameters are properly selected.

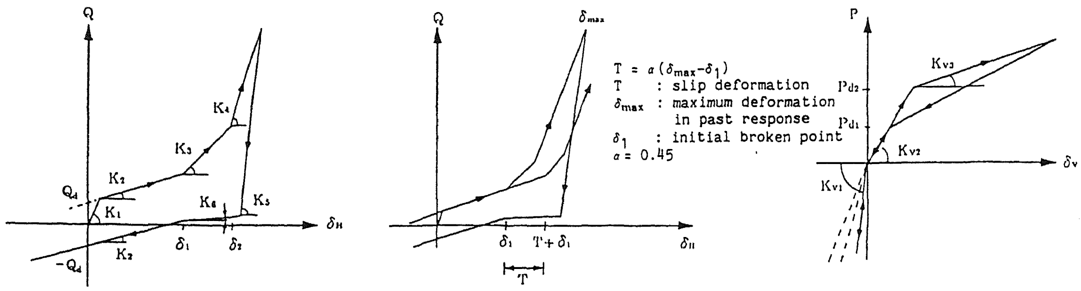
2 MULTI LINEAR MODEL

2.1 Analysis model

The multi linear model is proposed, based on the test data of LRB. The outline of the proposed mode are shown in Fig.1.

The skeleton curve of the horizontal hysteresis model consists of four lines. In the design level, the proposed model agrees with the ordinary bilinear model. In the large deformation, the hardening property is represented by two lines. The dependence of the iterative deformation in the hardening domain is represented by the slip model. The degrading of stiffness is evaluated by expanding the linear zone according to the maximum deformation which has experienced.

The skeleton curve of the vertical hysteresis model is represented three lines. The first line expresses the compressive stiffness, the second and third line express the softening stiffness in the tensile domain. In the tensile domain, the hysteresis loop returns to the middle of the second line.



(a) Horizontal model

(b) Evaluation of dependence of iterative deformation

(c) Vertical model

Fig.1 Hysteresis model by multi linear

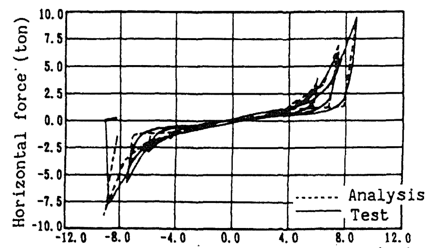
The dependence of the shearing deformation on the compressive stiffness is evaluated by reducing the compressive stiffness in proportion to the overlapped area of end plates in vertical projection.

The analysis results of the horizontal hysteresis loops are compared with the test results of the LRB whose vertical load is 2.2 ton(2.16×10^4N) and 150 ton(1.47×10^6N) (Fig 2). The analysis results agree with the test results in the hardening property and slipping behavior caused by the iterative deformation.

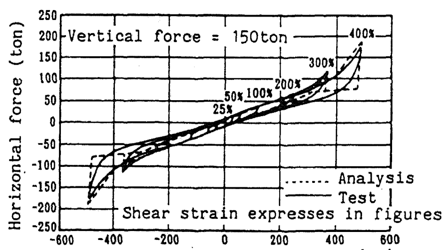
The analysis results of the vertical hysteresis are compare with the test results of 2.2 ton elements. Because the dependence of the iterative deformation are not considered in this analysis, the hysteresis loops by the analysis are not similar to the test results (Fig 3).

2.2 Earthquake response analysis

In order to investigate the effects of the properties of isolators on the dynamic behavior, the earthquake response analysis are performed. The superstructure which represents an FBR with base-isolated system is modeled by lumped masses with bending and shearing deformations(Fig.4). The superstructure is assumed to be linear. Soil-structure interaction is evaluated by a swaying and rocking spring. The isolators area modeled by five pairs of horizontal and



(a) 2.2 ton devices



(b) 150 ton devices

Fig.2 Comparison between analysis and test on horizontal hysteresis

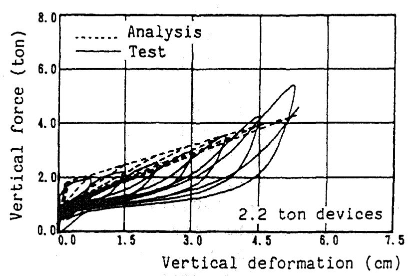


Fig.3 Comparison between analysis and test on vertical hysteresis

Table 1 Analysis modeles

No	horizontal dir. (dependence of iteration)	vertical dir.
1	ignored	nonlinear elasticity
2	ignored	hysteretic loop
3	ignored	hysteretic loop + dependence of shear deformation
4	considered	hysteretic loop

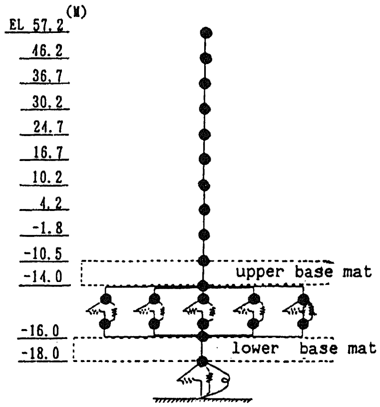


Fig.4 Analysis model for earthquake response

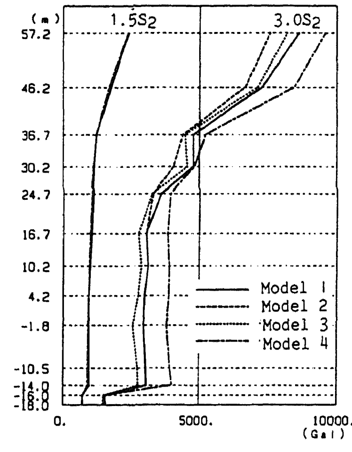


Fig.6 Distribution of maximum acceleration

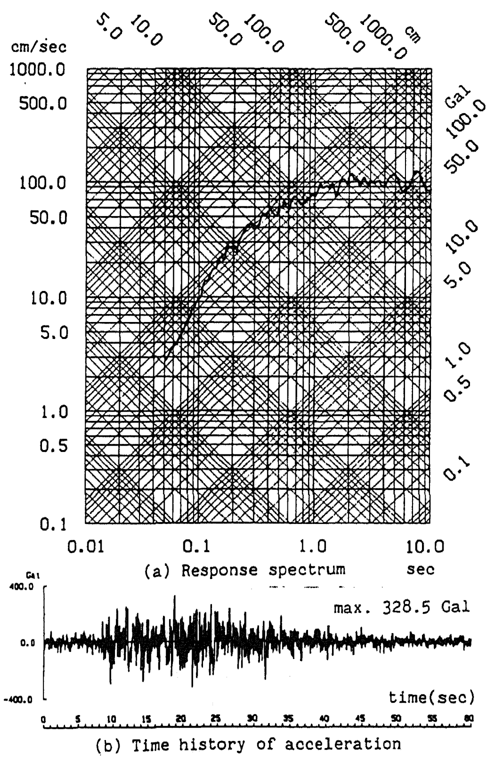


Fig.5 Input motion

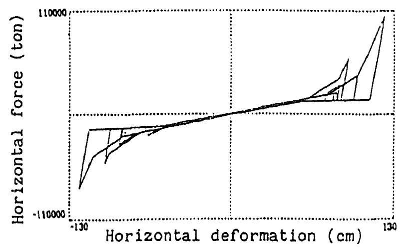


Fig.7 Example of horizontal hysteresis

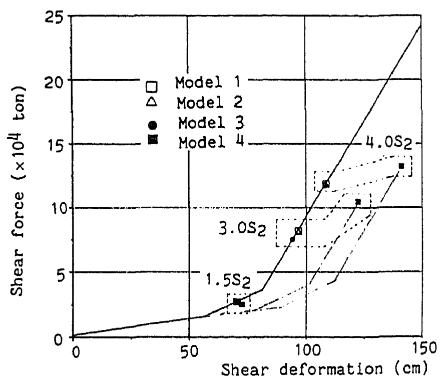


Fig.8 Maximum response on shear deformation-shear force plane

vertical spring whose properties are varied as shown in Table 1.

The tentative design earthquake ground S_1. motion for seismically isolated FBR(Ishida 1989) is enlarged, and used as the input motion.S_2 is assumed to be 1.5 times of S_1, and 1.5 S_2, 3.0 S_2 and 4.0 S_2 are used as the input level(Fig.5).

The earthquake response analysis results are shown in Fig.6~9.These results can be summarized as follows.

1) The magnification of the maximum response acceleration becomes large according to the increase of input level and the effect of the isolation becomes small because of the hardening characteristics.
2) In the maximum response acceleration of superstructure, the results of model 4 which consider the dependence of the iterative deformation in the horizontal

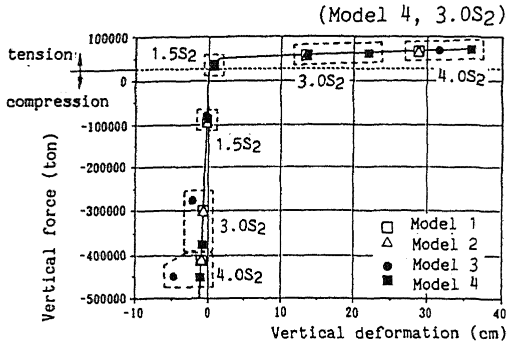


Fig.9 Maximum response on vertical deformation-vertical force plane

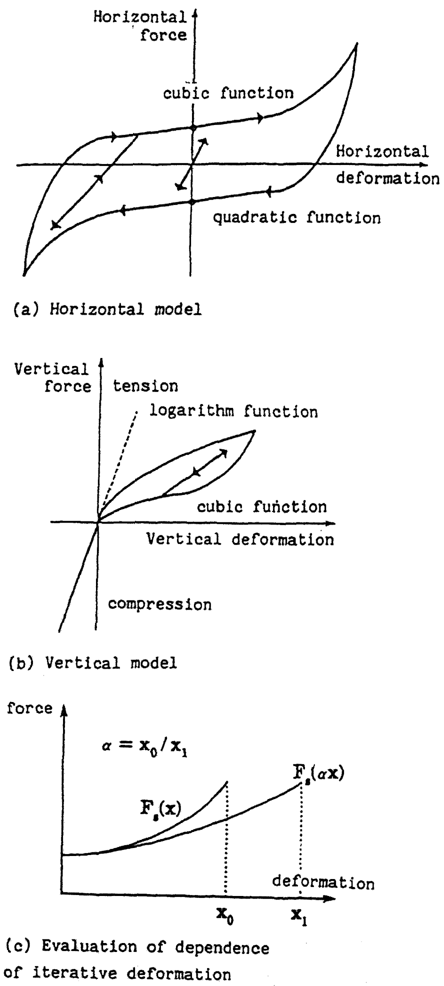


Fig 10 Hysteresis model by smooth function

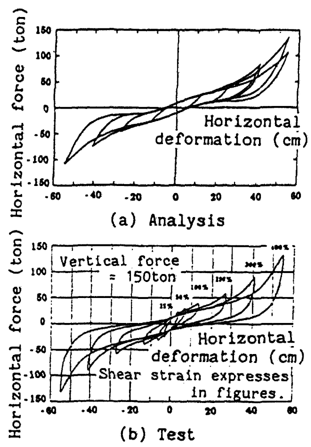


Fig.11 Comparison between analysis and test on horizontal hysteresis

characteristics become larger than the others over the 3.0 S_2.

3) In the horizontal deformation of the isolator, the results of model 4 become about 30% larger than the others. The tensile deformation at the end element becomes large in case of model 4, too.
4) The difference of vertical modeling doesn't affect the horizontal response.

3 SMOOTH FUNCTION MODEL

3.1 Analysis model

The smooth function model is proposed, based on the test data of HRB. The outline of the proposed mode are shown in Fig.10.

The horizontal restoring force model consists of the cubic function of the deformation as the skeleton curve and the quadratic function as the hysteresis loop.

In the vertical restoring force, the compressive stiffness is assumed to be linear. The restoring force model of tensile zone consists of the logarithm function as the skeleton curve and the cubic function as the hysteresis loop.

The dependence of the shearing deformation on the compressive stiffness is evaluated by reducing the compressive stiffness in proportion to the overlapped area of end plates in vertical projection.

The analysis results of the horizontal hysteresis loops are compared with the test results of the HRB whose vertical load is 150 ton(Fig 11). The constants of the skeleton curve is set up based on the monotonous loading test results.

The analysis results agree with the test results in the hardening property and slipping behavior caused by the iterative.

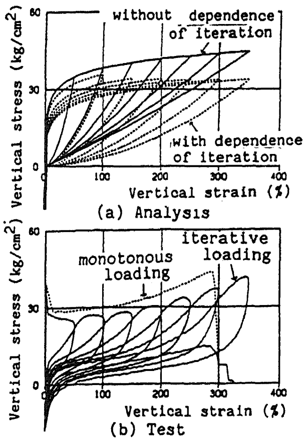


Fig.12 Comparison between analysis and test on vertical hysteresis

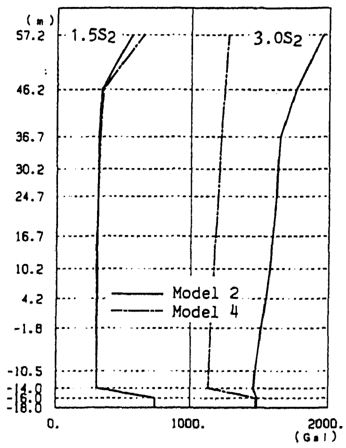


Fig.13 Distribution of maximum acceleration

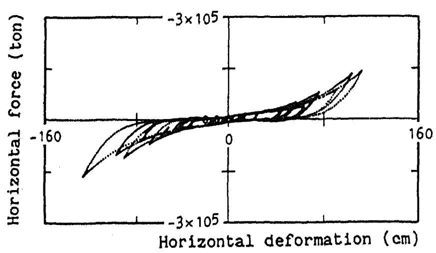


Fig.14 Example of horizontal hysteresis (Model 4, 3.0S2)

The analysis results of the vertical hysteresis are compare with the test results of 2.2 ton elements(Fig.12).

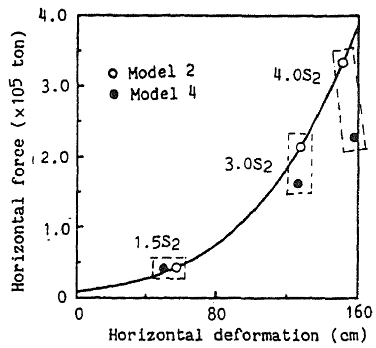


Fig.15 Maximum response on shear deformation-shear force plane

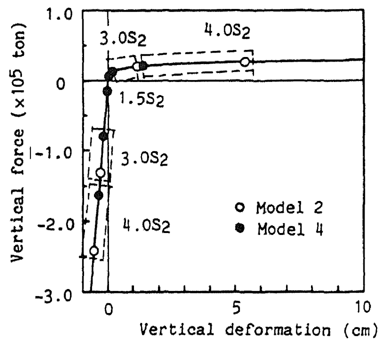


Fig.16 Maximum response on vertical deformation-vertical force plane

Two analysis results are shown in this figure. One is considered the dependence of iterative deformation. The other is ignored it. It was found that it is difficult to simulate the test results which represent very complicated behavior in tensile zone.

3.2 Earthquake response analysis

The earthquake response analysis are carried out in the same condition as the analysis of the multi;linear model. The analysis using model 2 and 4 in Table 1 are performed. In model 2, the constants of the skeleton curve are set up based on the iterative loading test results and in the model 4, the constants are set up based on the monotonous loading test results.

The earthquake response analysis results are shown in Fig.13~16.

In the maximum response acceleration at 3 S_1 input, the results of model 4 which consider the dependence of the iterative deformation in the horizontal characteristics become smaller than the others. It can be thought that the hardening shear stiffness of isolator which becomes hardening in large deformation are reduced by the effect of iterative deformation.

4 CONCLUSIONS

The dynamic properties of the isolators for the ultimate behavior are surveyed by the past experiment data, and the effective modeling techniques can be proposed. The earthquake response analyses are performed using the proposed models.

As the results, the following things are known.

1) The typical dynamic properties of isolators for ultimate states are the hardening of shearing stiffness , the dependence of the iterative deformation, the tensile hysteresis loop and the dependence of the shearing deformation on the compressive stiffness.
2) The hysteresis loop of the tensile zone is very complicated and it is difficult to express by a simple model.
3) The response magnification of the acceleration becomes large as the input level increases, and the effect of the isolation becomes small because of the hardening characteristics.
4) The earthquake response of the base isolation system for the ultimate behavior is severely affected by the iterative deformation of the isolators.

ACKNOWLEDGEMENTS

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