FEASIBILITY STUDY OF PSEUDO-DYNAMIC TEST METHOD BY A FULL-SCALE SIMPLE STRUCTURE

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SUMMARY

This paper presents a pseudo-dynamic test on a full-scale two story steel frame conducted to verify the applicability of the new test method to full-scale building structures. This test, at least in Japan, was the first attempt to apply the test method to a full-scale structure for simulating seismic behavior. The test results were compared with several response analyses in some aspects. By this study, the validity of the test method were confirmed in a full-scale structure phase.

INTRODUCTION

Originally, the pseudo-dynamic(PSD) test using computer-actuator on-line system was conceived to develop an understanding of seismic responses of complicated structure systems, which would not always be estimated even by great computational effort or scaled model test. In this sense, the advantage of the new test method depends mainly on its applicability and testing technique, including facilities, to full-scale structures.

This paper reports on pseudo-dynamic test results on a full-scale two story steel frame conducted to verify the feasibility of the test method to full-scale building structures, utilizing the Large-Scale Testing Facilities in the Building Research Institute(BRI).

TEST SCHEME

To define the correlation between the test and response analysis, a specimen with simple and predictable hysteresis behavior was needed. A two story steel frame with slender diagonal braces was prepared for this purpose.

Test Structure

The shape and dimensions of the test structure are shown in Fig. 1 together with the actuators and load distribution beams. The structure had two identical planner frames to prevent out-of-plane action. Flat-bar section was shosen for the diagonal braces to make buckling loads extremely low. Thus, the hysteresis behavior of the braces was expected to be of a so-called slip type by this design.

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The weak-axis of the H-shaped columns was proportioned in the transverse direction of loading. Moreover, the beam-to-beam connections were designed to be of a shear type, that is, only the webs of the beams were jointed each other by high strength bolts. By this treatment, moment-frame action resisting lateral forces was anticipated to be little. Therefore, the story restoring force characteristics of the test structure would depend primarily on the behavior of the diagonal braces.

The mechanical properties of the used steels for the members are listed in Table 1. By using these values, the stiffness and strength etc. of the specimen were calculated as shown in Table 2.

Instrumentation

Lateral displacements at each floor level were measured by inductance-type transducers at the midspan of the transverse beams (Fig.1). These analog signals were converted into digital values to control each actuator motion for the PSD test system.

Around two hundreds wire-strain gages were sticked on the braces and the top and bottom of the columns, in order to estimate each share of shear forces between the braces and the surrounding frames.

Test Procedure

The central difference numerical integration method was used for the computer program of the PSD test. This numerical technique does not need the stiffness of specimens, which is essential for the linear acceleration method, but needs only reaction forces of the specimens. The numerical procedure is most adequate for the PSD test, if the time interval of calculation is sufficiently short (see Eq.(1)).

To calculate the next-step command (at i+1 time-station) for actuators by the numerical method, the present (at i) and preceding (at i-1 and i-2) displacements are needed. Hereby, there are two kinds of displacements at i, i-1 and i-2 time-stations. One is the measured displacement, and the other is calculated one (command displacement). As a conclusion by many preliminary tests and analyses, it was found that the calculated displacements should be used to compute the next command displacements.

Test Prameters

The weight at each floor level was assumed to be 70 ton for the PSD test. For the assumed weight, the first and second natural periods of the structure were 0.431 sec and 0.177 sec, respectively.

For the purposes of the PSD calculation, structural damping was assumed to be of the viscous type. Furthermore, the damping matrix [C] was assumed to be proportional to the initial stiffness matrix [K] of the structure. Then, the damping matrix was determined by adopting 1% damping ratio for the first natural period.

The time interval Δt for the numerical integration in the central difference method would be preferable to be taken no larger than the following criteria(Ref. 1);

$$\Delta T = Tmin. / 6\pi \qquad (1)$$

where Tmin. is the minimum natural period of the structure concerned . In this case, Tmin./6π is 0.0094 sec so that the calculation by Δt=0.01 sec would be permissible in practical sense.

The input acceleration used in this study was the N-S component of the El Centro Earthquake (1940) accelerogram, in which maximum acceleration was 314.5 gal. This record was directly employed without scaling in acceleration and time.

EXAMINATION OF RESULTS

Response Waveforms

Fig. 4 shows displacement time histories at each floor level by both the test and response analyses. The central difference analysis (I) and linear acceleration analysis were done, before the test, by using the restoring force characteristics as shown in Fig. 3 and assuming a two degrees of freedom lumped mass system. The difference between these analyses can be seen to be little. The central difference analysis (II), on the contrary, was performed after the test, estimating slight shear forces shared by the columns and initial slippage in the story shear-story drift relation, as will be discussed in the next section. This modified analysis could make the response closer to the test displacement at both floor levels than the other two analyses.

Shear force waveforms obtained by the actuator loads are shown in Fig. 5, with the results of the central difference analysis (II). In this figure it may be observed that, for the large amplitudes of response given, the analytical results agree well with the test results.

Restoring Force Characteristics

Solid lines in Fig. 6 indicate the story shear-story displacement relations obtained by the experiment. The hysteretic behavior of each story was almost realized as a slip model like Fig. 3. However, as can be seen in Fig. 6, especially in the first story relation, slight slopes are not only in post-yielding flows but in slip regions. This behavior was due to slight moment-frame action, that is, the frame surrounding the braces shared the lateral loads with the braces. The shear forces imposed on the columns could be calculated by the strains of the columns measured with the strain gages. Fig. 7 shows the relations between the story drift and the shear force extracted by the calculation. Subtracting the shear forces of Fig. 7 from those of Fig. 6 along the hysteresis, hysteretic behavior of the braces was indirectly obtained as shown in Fig. 8. This behavior would be quite similar to the hysteresis model of the braces assumed in the analyses (Fig. 3), and be supported well by the direct measurement of strains of the braces as shown in Fig. 9.

Again in Figs. 6 and 8, for the first story relations, the initial slippage can be seen around the origins. This might be due to initial imperfection at installing the braces. The amounts of slippage were 2.27 mm in the positive sign of loading and 3.18 mm in the negative direction respectively.

The central differenece analysis (II) incorporated the shear forces by the moment-frame action and the initial slippage, in the hysteresis model of restoring force characteristics. The shear forces in the columns were approximated with slanting straight lines through the origins as shown in Fig. 7. The analytical results were plotted in Fig. 6. The correlation between the test and the analysis is considerably good. However, some difference in story drift response can be observed between the test and the analysis. A reason for this discrepancy would be conceivable. It is associated with the difference in story yield strength between the test and the analysis. In the analysis, the nominal areas of the braces and the yield stresses obtained from coupon tests were used to calculate the yield strength of each story. The actual yield strength gained by the PSD test, however, was rather different from the calculated strength, as shown in Fig. 8. As can be readily recognized, such discrepancy in force level would affect sensitively displacement responses.

The over-all correlation between the test results and the analysis can be found satisfactory, despite the above-mentioned difference in the estimation of story yield strength. By this correlation, it can be said that the PSD test, including the test facilities, for full-scale structures, has much feasibility and reliability.

DEVELOPMENT OF PSD SYSTEM AT BRI

Through this pilot test, the PSD test system at BRI was much developed in several phases. They were the digital measuring of specimen displacements, the piecewise loading, and the interactive control between actuator and specimen displacements. The detailed description on the developed BRI system is presented by our colleagues at this conference (Ref. 2).

CONCLUSION

The PSD test was performed by using the two story diagonally braced steel frame having simple and predictable hysteretic behavior. The feasibility and applicability of the test method were confirmed for a full-scale structure phase, by the comparison in the test results and analytical ones. The PSD test system at BRI was much developed by the pilot test.

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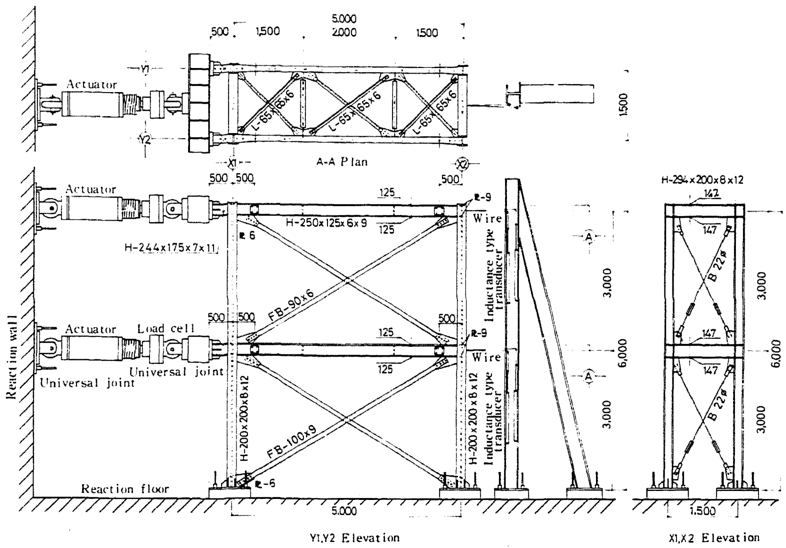


Fig. 1 Dimensions and Set-Up of Specimen

Teble 1 Mechanical Properties of Steels by Coupon Tests

	σy (t/cm^2)	σu (t/cm^2)	εy (%)	εst (%)	εu (%)
Brace(1F)	3.16	4.65	0.15	1.78	25.67
Brace(2F)	2.87	3.87	0.16	2.44	26.33
Beam	3.69	4.94	0.18	2.49	30.0
Column	3.14	4.79	0.19	1.53	23.0

σy; yield stress
σu; tensile strength
εy; yield strain
εst; strain at strain-hardening
εu; strain at fracture

Table 2 Properties of Specimen

	Sectional Area of Braces cm^2 (nominal)	(measured)	Rigidity ton/cm	Yield story shear coefficient	Yield story shear (Qy) ton	Yield story displacement (σy) cm	Ultimate story shear ton
1F	9.0	8.86	46.67	0.348	48.73	1.020	71.49
2F	5.4	5.44	28.60	0.380	26.58	0.929	35.75

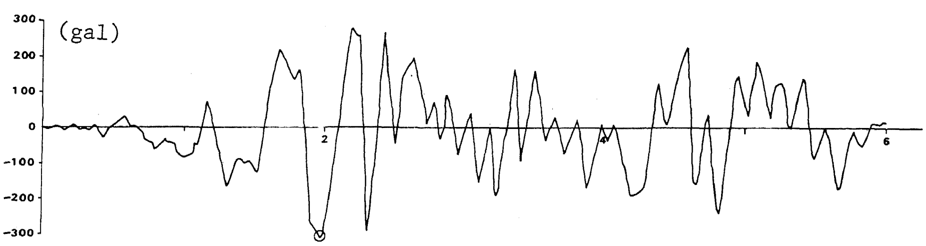


Fig. 2 Time History of Input Ground Motion

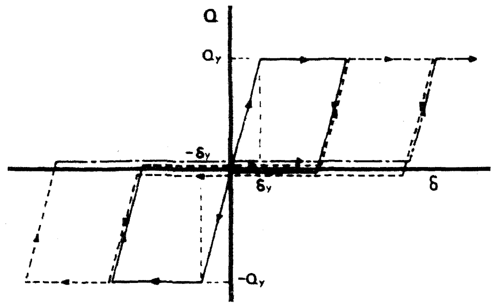


Fig. 3 Shear Force-Displacement Relation Assumend in Preliminary Analysis

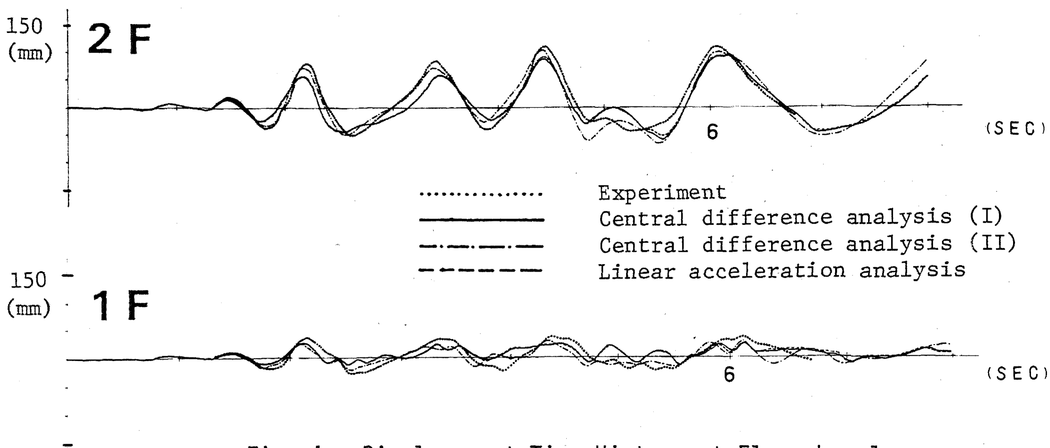


Fig. 4 Displacement Time History at Floor Levels

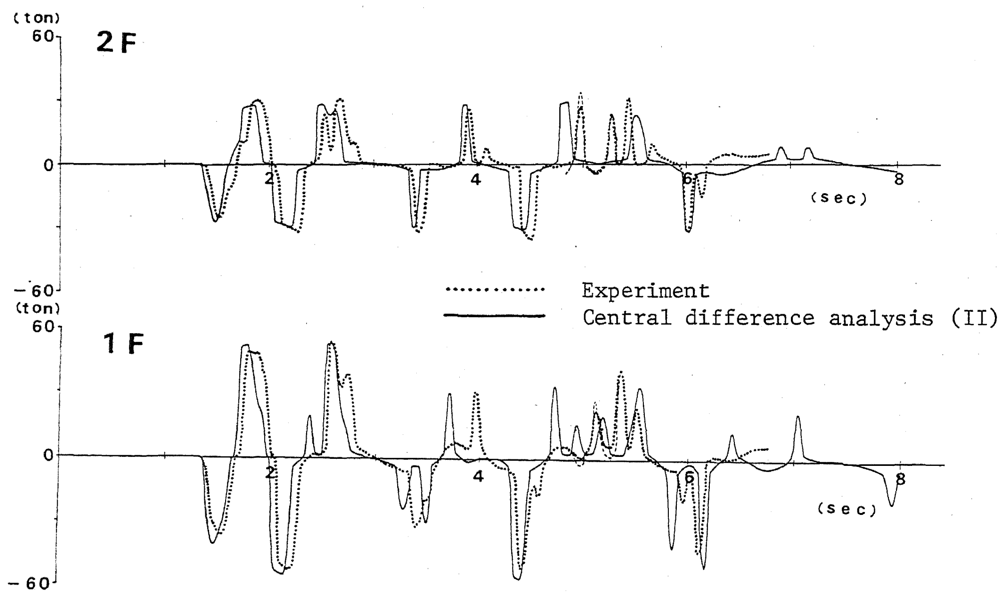
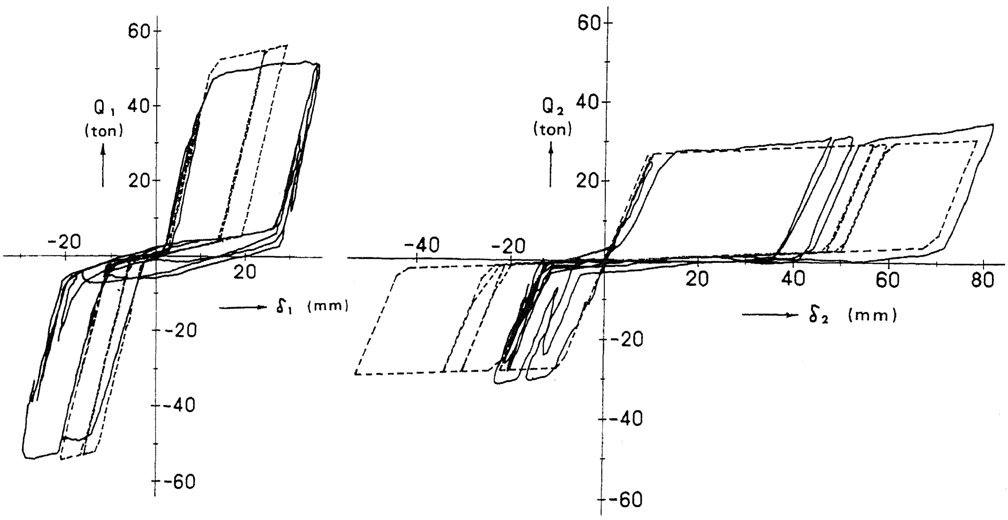
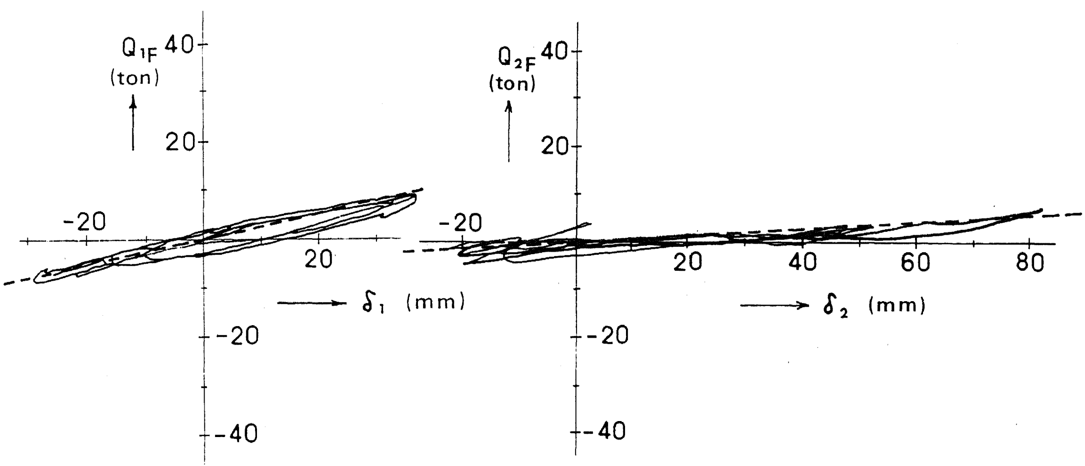


Fig. 5 Shear Force Time History in Stories



Experiment
Central difference analysis (II)

Fig. 6 Story Shear Force and Displacement Relationship



Approximate moment-frame action
used for modified analysis

Fig. 7 Moment-Frame Action in Story Shear Force and Displacement

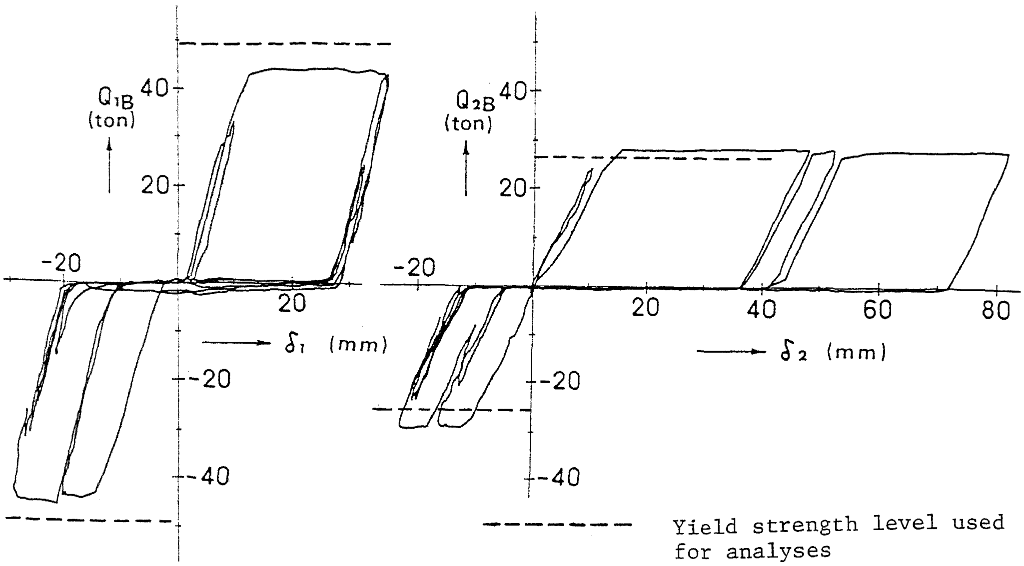


Fig. 8 Indirect Relation between Shear Force and Displacement of Braces

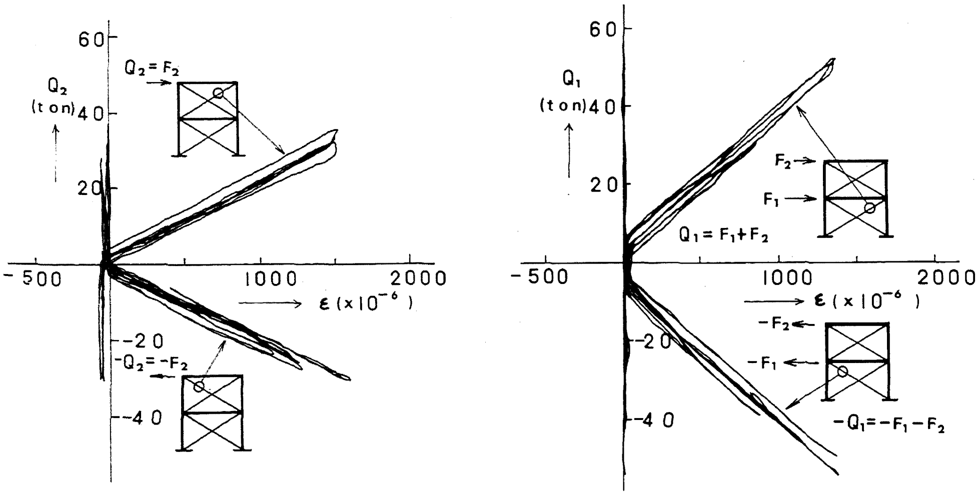


Fig. 9 Shear Force and Strain Relation of Braces