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STUDIES ON EARTHQUAKE RESPONSE OF MULTI-STORIE BRACED FRAMES USING MULTI-POINT PSEUDO DYNAMIC TESTING METHOD

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SUMMARY

This paper presents the multi-point pseudo dynamic testing (MPD) on a three-story braced frame and corroborative analysis. Dynamic behaviors of braced structures for power plant buildings subjected to a strong earthquake motion are investigated through elastic and plastic range. From the results of tests and analyses, it is confirmed that the eccentrically braced frames (EBF) and the inverted-Y braced frames (YBF) with a shear link between brace and beam show more excellent structural performances than the centrally braced frames (CBF) and that the developed analysis method is able to simulate their complicated behaviors including yielding and buckling, which both mean that a more rational approach would be possible in the actual design procedures.

INTRODUCTION

The CBF has been used as an earthquake-resisting structure for the thermal power plant buildings, although vulnerability due to buckling is considered fatal when affected by severer loadings than expected. Several special bracings have been recently proposed in order to avoid brittle failure by adding shear link as evergy absorbing element in the frame. Among them, the EBF is reported (Ref.1) to be distinguished owing to its simple mechanism and to high ductility. The YBF is being considered as proposed based on the same intent as on the EBF. However, as the EBF is rarely used in Japan and research on the YBF is still limited, it becomes necessary for engineers which look for better structural systems for a power plant buildings, such as boiler and turbine houses, to get specific structural features on the elastic and plastic behaviors during strong earthquake. The objectives of this study are to obtain the elastic-plastic characteristics of each braced frame, to make comparisons with each other from the view point of structural performance and to verify further the computer analysis method that has been used in the practical design procedures.

TEST PROGRAM

Specimens Three specimens of one-span three-story braced steel frames are tested as shown in Fig.1. The dimensions of column and beam are common to all specimens but the braces are different from each other. Referring to the foregoing report, the EBF and the YBF are designed under the condition that the link will yield due to shear in the beginning when the neighboring braces are affected from 80 percent axial stress of its buckling strength in case of lateral loadings. Braces of the CBF are, on the contrary, designed to buckle also under the loading with the same story shear that the other two specimens will also yield. Braces have the slenderness ratios between 90 and 100 and carry approximately 90 percent of the entire lateral loads before buckling.

Test Conditions The MPD is carried out using an earthquake record of the SENDAI TH038 NS component at the Miyagioki earthquake of June 12, 1978 shown in Fig.2. The maximum acceleration is modified to be 200 Gal for elastic test and 1000 Gal for elasto-plastic test. In order to compare the test results in the same light, the fundamental period of the specimen was selected to be 0.225 second in common, which coincides with the second peak value of the response spectrum of the earthquake in Fig.3. As can be seen from the figure, the time scale of the record is reduced to be 1/5 of the original, and an incremental time interval for computation during the MPD is 1/400 second. Viscous damping is assumed and introduced in the form of a matrix proportional to an elastic stiffness matrix with damping factor of 0.03 which is unchanged during the test. In order to obtain the elastic stiffness and to decide virtual mass on the floor, a unit load is independently applied to every floor. Loadings are conducted using three actuators to alternatively apply lateral force to the floor slab through a special device. Displacement of 60 points and strains at 200 locations are recorded and compiled in the data processing device.

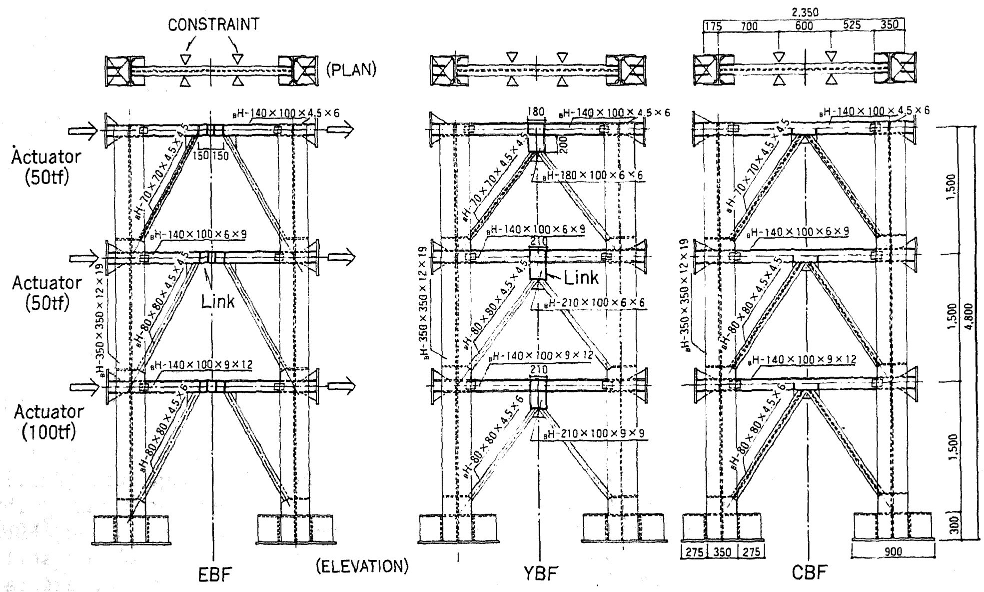


Fig.1 Test Specimens

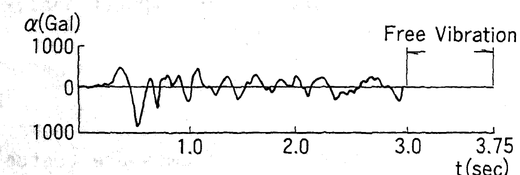


Fig.2 Input Ground Motion
(SENDAI 038 NS, 1978.6)

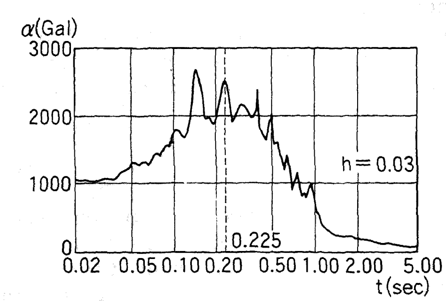


Fig.3 Relation of Response Spectrum and Natural Period

TEST RESULTS

From the results of unit force loadings, the weights of each floor of the EBF, YBF and CBF were decided on 15.7 tf, 24.2 tf and 25.2 tf respectively. The fundamental periods of all test structures were confirmed to be 0.225 second throughout the MPD by an artificial input ground motion that has a constant acceleration amplitude with gradual decreasing frequencies.

Due to the dynamic characteristics common to all structures, their response behaviors at 200 Gal's input earthquake are all alike as shown in Fig.4, where the displacement time histories of the third floor are plotted. Mode shapes of all the structures during the earthquake excitation are the so-called shear type and small amounts of negative shear that is induced in the opposite direction against loading are observed in the third floor braces.

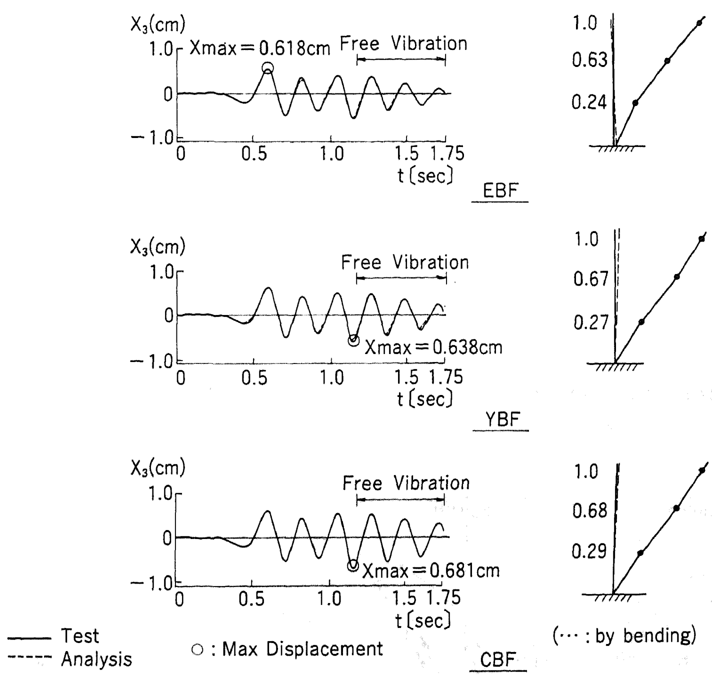


Fig.4 Displacement Time History (3rd story) and Mode Shape

Acceleration and displacement time histories at the third story are shown in Fig.5 and Fig.6. Both of the shear-link at the each story in the EBF and the YBF yielded at 0.42 ∿ 0.50 second after the beginning of excitation. The brace at the each story also buckled approximately at the same time soon after the first peak amplitude with maximum acceleration of 1000 Gal occurred. Mostly all of failures of the structural elements, although not destructive, follow successively resulting in large residual deformations. Despite the similar acceleration behaviors of all structures, displacement responses are much different from each other, where the CBF is deformed with the largest displacement, 6.4 cm, at the third story. Crack is found especially at the third story's brace ends of the CBF.

Relationships between story shear force (Q) and lateral displacement (δ) at the second story are shown in Fig.7. Those at the third story have similar tendencies while those at the first story remain in semi-elastic region. It is clearly recognized that both the EBF and the YBF have stable restoring force characteristics without deterioration of load carrying capacity while the CBF has a somewhat poor one. Deformability of the structure is, however, satisfactorily large up to 1/60 radian of deflection angle.

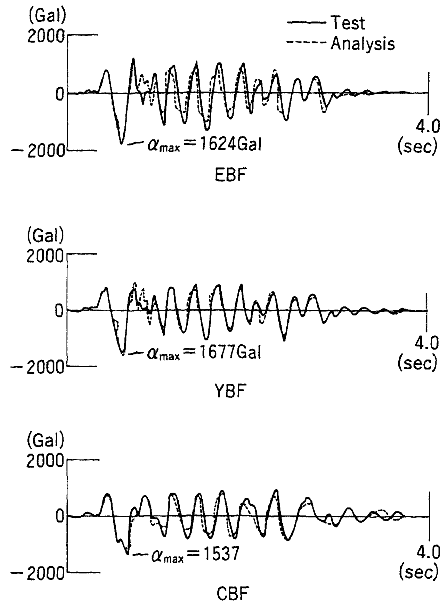


Fig.5 Acceleration Time History (3rd story)

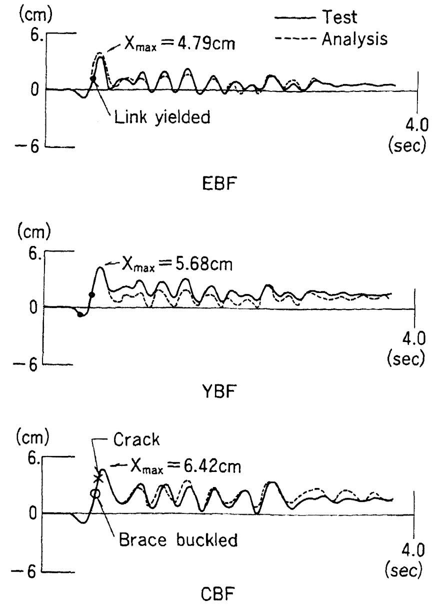


Fig.6 Displacement Time History (3rd story)

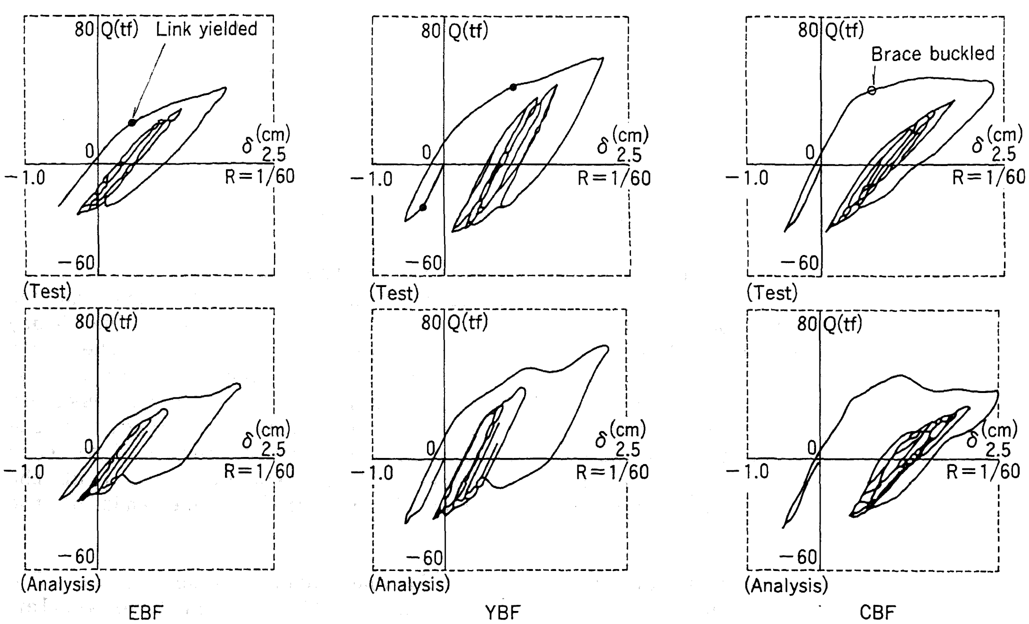


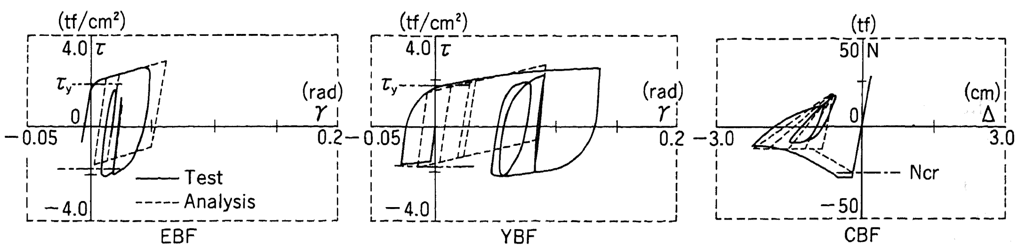
Fig.7 Relationship between Shear Force and Horizontal Displacement (2nd story)

Relationships between shear stress (τ) and shear deflection angle (γ) of the link are shown in Fig.8 as well as that of axial force (N) and axial deformation (Δ) of the brace. As for the energy absorbing capacity, it is confirmed that the shear links have stable restoring force characteristics that is idealized by bilinear type hysteresis model with harding factor of 0.02~0.04. Restoring force characteristics of the brace is a little complicated but can be replaced through the formulation.

Fig.9 shows vertical displacement of the joining portion of the second floor beam of each structure when maximum lateral displacement occurs. Caused by the yield of beam and by the buckling of brace, large rotations of link and severe shortening of brace result in larger vertical deformations of the EBF and the CBF respectively. Since the brace remains elastic, the vertical deformation of the beam of the YBF is quite small.

SIMULATION ANALYSIS

Using the computer program developed for the dynamic analysis of the braced structure (Ref.2), the specimens' behavior under the test conditions were sepa-



a) Shear Stress-Strain Curves of Link

b) Axial Force-Axial Displacement Curves of Brace

Fig.8 Restoring Force Characteristics of Link and Brace

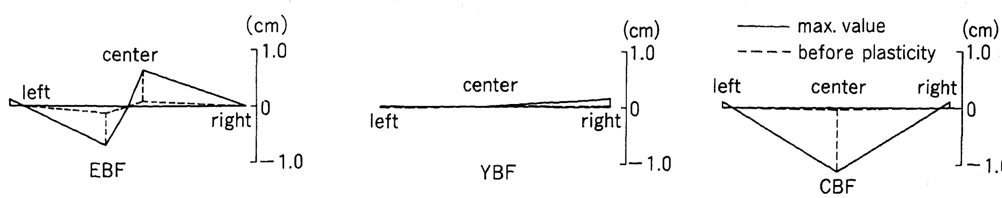


Fig.9 Vertical Displacement of Beam

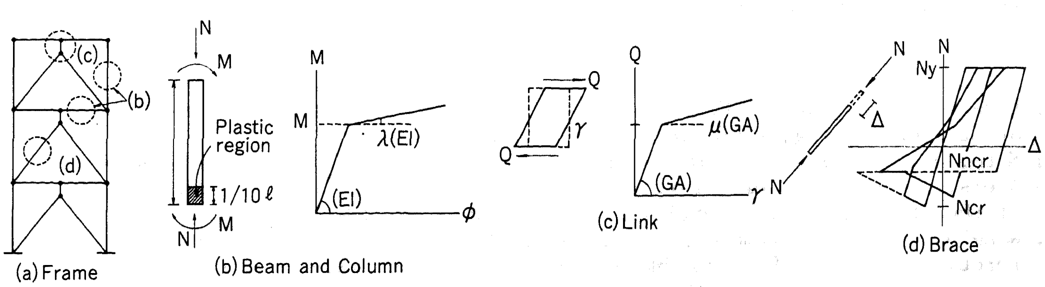


Fig.10 Analytical Model and Presumed Hysteresis of Element

rately simulated. As described in the reference, the program is able to take into account the elasto-plastic properties due to the buckling of the brace as well as the yielding of the column and beam. An analysis model of the entire structure and restoring force characteristics of structural elements are shown in Fig.10 (a) to (d).

It is assumed that the structure is composed of column, beam, link and bracing. The stiffness matrix of column and beam are constructed by the general plastic hinge theory where the nonlinearity is defined at the 1/10 length's region from the end of the member. Bilinear type nonlinearity of the link is introduced from the test findings, while the brace is characterized and formulated by the previous studies in regard to axial stiffness (Ref.3).

Results of the response calculations in case of the elastic and elasto-plastic test conditions are already concurrently plotted in the figures of the test results in the form of the acceleration and displacement time histories as well as that of $Q-\delta$ relations. The linear response results against 200 Gal earthquake are almost identical to the tested ones. As for the elasto-plastic responses against 1000 Gal earthquake, although small discrepancy can be recognized, it may safely be said that the computer program is adequate to reproduce the complicated behaviors of the structure tested with consideration for the high intensity of ground motion.

CONCLUDING REMARKS

Through the knowledges obtained by the MPD on the braced frames, it is concluded that, more or less, they have sufficient ductility and deformability without loss of the load carrying capacity. Restoring force characteristics of the braced frames with shear links is relatively more stable with large energy absorbing capacity. However, considerable amount of deformation at the joining portion should be taken into acount in the design practices.

The analysis method, where all the structural elements are presumably modeled on precedent theory and experiment, is verified by getting the simulated results fairly coincided with the MPD results even in case of an extremely large earthquake intensity of 1000 Gal. Therefore, practical design in consideration of post yielding as well as post buckling could be relevant to the planning of the power plant buildings.

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