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APPLICATION OF NEW R/C MATERIALS TO MEGASTRUCTURAL BUILDING SYSTEMS IN SEISMIC ZONES

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ABSTRACT

Introduced is feasibility study on structural design of megastructural building systems utilizing the New RC materials. Emphasis is placed on the seismic design for the New RC buildings in the zones where high seismic activities are expected. Design criteria assuring structural safety against seismic lateral loads are proposed. Six megastructural building systems, which are 200m or 300m in height composed of frames with/without braces, are designed according to the proposed design criteria.

The building system is designed, in principle, against lateral loads following the weak beam-strong column concept forming a beam side-sway mechanism in its ultimate stage.

Design criteria assuring structural safety against seismic lateral forces are proposed for the New RC megastructural building systems. Six megastructural building systems with/without braces are designed, of which three are 200m in height and other three are 300m in height. These designed building systems are examined their structural properties to meet the requirements introduced in the design criteria.

Feasibility study on the structural design of megastructural building systems utilizing the New RC materials is conducted. Examination by dynamic analysis leads to the conclusion that high-rise megastructural building systems can be constructed in seismic zones such as Japan with application of the New RC materials.

After all the building systems were designed, "The 1995 Hyogo-Ken Nanbu Earthquake" occurred. The deflection responses of several building systems are examined using the Kobe Marine Meteorological observatory North-South component of this earthquake and Sylmar 1994 N-S.

KEYWORDS

High-strength concrete; High-strength steel bars; seismic design; megastructure; the 1995 Hyogo-Ken Nanbu Earthquake; the 1994 Northridge Earthquake

INTRODUCTION

Recent development of the New RC materials makes it possible to construct high-rise buildings using reinforced concrete system composed of structural members having acceptable dimensions. In this paper, examined are feasibilities of structural design, in particular of seismic design, of high-rise megastructural building systems utilizing the New RC materials in the zones where intense seismic activities are expected.

Six high-rise megastructural building systems are studied by a technical committee mentioned at the end of this paper. These six systems shown in Figure 3 can be grouped into those ; (1) that are 200m in height and 300m in height, and (2) that are so-named open frame buildings composed of beams and columns and so-named braced frame buildings placing braces within an open frame. The six systems are as follows.

(1) an open frame building with straight elevation of 200m height (OP200S)
(2) an open frame building with straight elevation of 300m height (OP300S)
(3) an open frame building with tapered elevation of 300m height (OP300T)
(4) a braced frame building using K-shaped braces with straight elevation of 200m height (BR200K)
(5) a braced frame building using diagonal braces with straight elevation of 200m height (BR200D)
(6) a braced frame building using X-shaped braces with straight elevation of 300m height (BR300X)

NEW RC MATERIALS AND SYSTEMS

Both concrete and steel bar that are high in strength have been developed. Hereinafter these concrete and steel bars having high strength are called the New RC materials, and RC systems utilizing the New RC materials are defined as New RC systems.

The compressive strength of concrete in the New RC system shall be greater than 30MPa, and the strength of steel reinforcing bars greater than 390MPa. The concrete whose compressive strength is greater than 60MPa and steel bar whose strength greater than 685MPA can be named the ultra-high strength concrete and steel bar, respectively. In this examining feasibilities of structural design of megastructural RC buildings herein, the New RC systems by using these ultra-high strength concrete and steel bars are employed.

STRUCTURAL DESIGN CRITERIA

Principles of the design criteria

Principles of the design criteria are as follows. For the dead, live and other permanently acting loads, the working stresses of structural members are calculated, and the working stresses are ascertained to be less than the allowable stresses specified for both concrete and steel reinforcing bars. For seismic loads, based on the elasto-plastic load-deflection characteristics determined from the ultimate strength of constituent members, the following two items are ascertained. First, through dynamic response analysis, both story drift responses of the building and member ductility factors shall be less than those specified. And secondly, through static frame analysis, at the prescribed deflection, hinges shall not be formed that are not expected during the structural design and the member ductility factors of hinges at the location where expected shall be less than those figures that are specified.

The building system is planned, in principle, to be designed against lateral loads following the weak beam-strong column concept forming a beam side -sway mechanism in its ultimate stage.

Design criteria for dead and live loads

The design loads are established as provided in the Building Standard Law Enforcement Order in Japan, and the allowable stresses of concrete and steel reinforcing bar are prescribed tentatively as tabulated in Table 1 modulating the specification in the Standards.

Design criteria for seismic loads

<u>Design criteria in dynamic frame analysis</u>

The designed megastructural building system shall meet the following criteria through dynamic response analysis.

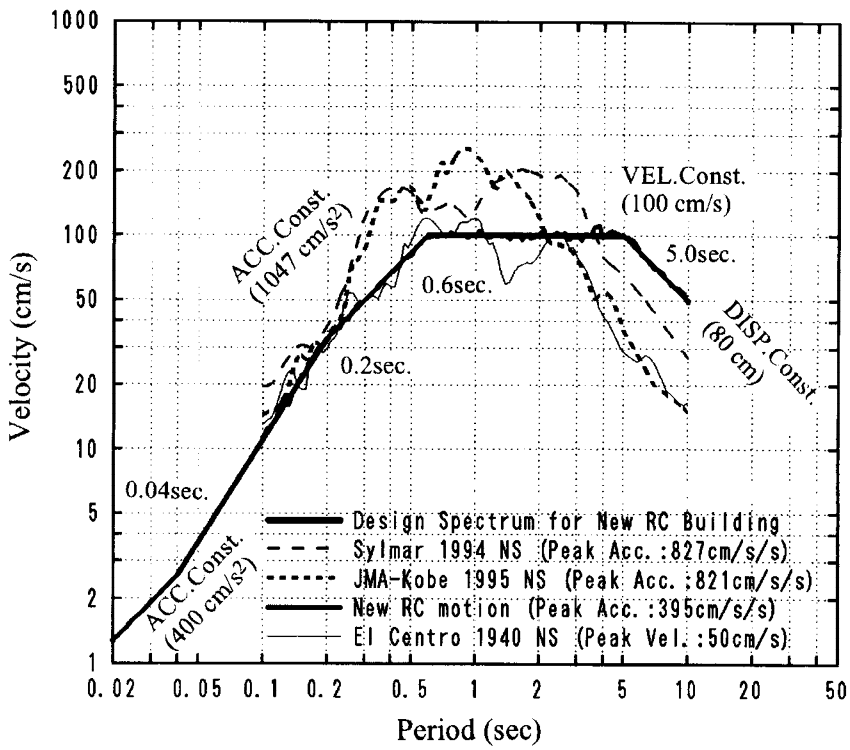

Fig.1 Design for NewRC buildings and Response spectra of some waves of ground motions for dynamic analysis

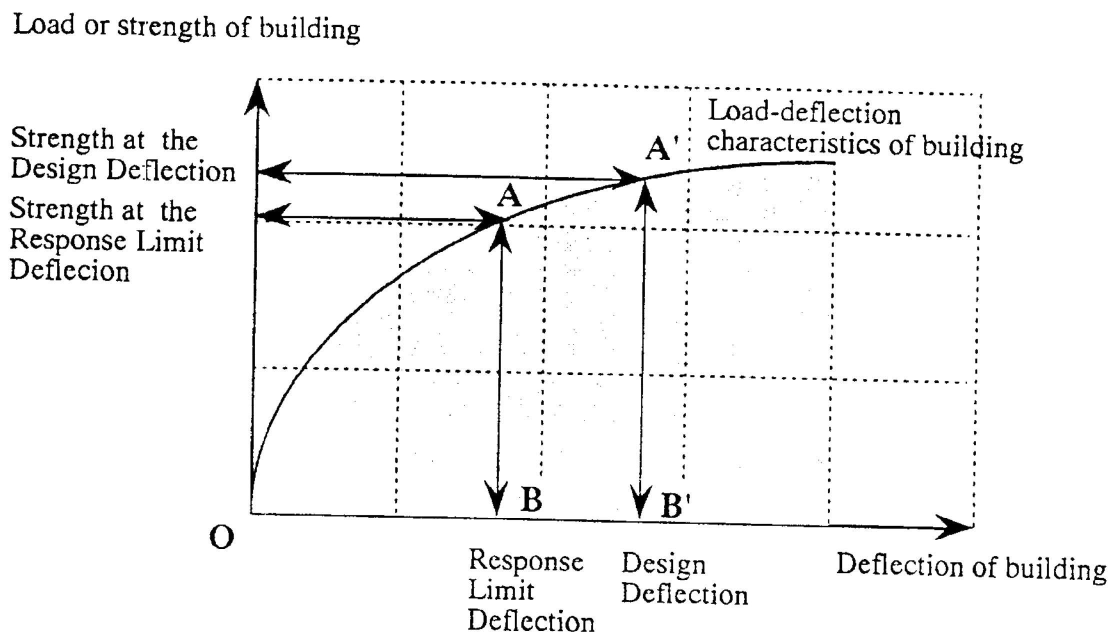

Fig.2 Load-deflection or strength-deflection of a building system in correlation with the "Response Limit Deflection" and "Design Deflection"

Table 1 Allowable Stresses for Dead and Live Load

	Allowable stresses for permanently acting loads
Concrete	Fc/3 (Compressive stress)
Steel reinforcing bars	195 MPa (Tensile and shear stresses) $2/3\sigma y$ (Compressive stress)

Fc: the design standard strength of concrete
σy: the nominal yielding strength of steel reinforcing bars

(1) Responses when subjected to the Level I seismic motions shall fulfill the conditions that ;
  (a) the maximum story drift angle at every story is less than 1/200.
(2) Responses when subjected to the Level II seismic motions shall fulfill the conditions that ;
  (a) the maximum story drift at every story is less than the "Response Limit Deflection,"
  (b) the member ductility factors of constituent structural elements are less than 1.0.

Seismic motions

In the dynamic response analysis, two levels of seismic intensity, the Level I and II, shall be employed.

The Level II earthquake motions will represent the maximum credible seismic motions at the construction site. Level II synthetic earthquake motion for the New RC structural systems, called "the New RC motion", have been generated, whose spectral diagram is shown in Figure 1. It is considered that, a building can be subjected to the New RC motion (Level II), once within a 20 percent chance over a 100-year period, near Tokyo. When one uses real earthquake motion records, one shall modulate the amplitudes of acceleration so as the peak ground velocity to be 50cm/sec.

The Level I earthquake motions are representative of the maximum possible seismic motions. A building can be subjected to the Level I earthquake motion once within a 60 percent chance over a 100-year period. To obtain the Level I earthquake motions, one multiplies the amplitudes of the New RC motion by 0.4, or modulates the amplitudes of real earthquake motions yielding the peak ground velocity of 25cm/sec..

Structural modeling

One shall carry out an elasto-plastic response analysis. The elasto-plastic characteristics shall, in principle, be determined based upon constituent structural elements.

Design criteria in static frame analysis

The designed megastructural building system shall meet the criteria defined in the following.
(1) Results of a static frame analysis shall fulfill the conditions that ;
  (a) hinges are not formed in the structural elements at the "Design Deflection" except those initially planned,
  (b) the member ductility factors of constituent structural elements are less than 2.0 at the "Design Deflection."

The "Design Deflection" is determined from the prescribed "Response Limit Deflection," specified for the building. The "Design Deflection" is defined by the deflection at the centroid of the static seismic lateral loads relative to the base of the building. The deflection at the centroid of the static seismic lateral loads will be taken to represent uniquely the deflection of the building, indicating probable response deflection, on an average, during seismic excitation. Figure 2 illustrates the schematic correlation of the "Response Limit Deflection" and "Design Deflection." The "Design Deflection" is determined so as the area enclosed by a set of curves O-A', A'-B' and B'-O to be twice or more times as large as the area enclosed by a set of curves O-A, A-B and B-O, where point B and B' denote "Response Limit Deflection" and "Design Deflection", respectively.

DYNAMIC ANALYSIS AND DISCUSSIONS

Through a dynamic response analysis, the following four seismic accelerograms are utilized.
  (1) the El Centro N-S component of the 1940 Imperial Valley Earthquake
  (2) the synthetic New RC motion (Phase angles are determined by uniformly distributed random numbers)
  (3) the JMA-Kobe N-S component of the 1995 Hyogo-Ken Nanbu Earthquake
  (4) the Sylmar County Hospital N-S component of the 1994 Northridge Earthquake

Figure 4 shows the results of dynamic response analysis of the maximum response displacements, the maximum story drift angles and the maximum shear coefficients. The maximum drift angles are almost less than 1/100, the value prescribed in the design criteria, to the four motions. The maximum response drift angles are obtained from the analysis using the NewRC motion or Sylmar 1994 NS in many cases. It is supposed that the velocity response spectrum does not get smaller even in the area longer than 5 or 3 sec..

CONCLUDING REMARKS

Feasibility study on structural design of megastructural building systems utilizing the New RC materials is conducted. Emphasis is placed on the seismic design for the New RC buildings constructed in the zones where high seismic activities are expected.

Design criteria assuring structural safety against seismic lateral forces are proposed for the New RC megastructural building systems. These designed building systems are examined their structural properties to meet the requirements introduced in the design criteria. Examination and discussion on the feasibility study, leads to the conclusion that with application of the New RC materials high-rise megastructural building systems can be planned in the area where intensive seismic activities are expected.

ACKNOWLEDGMENT

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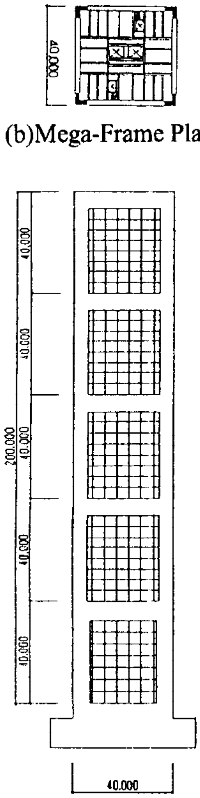
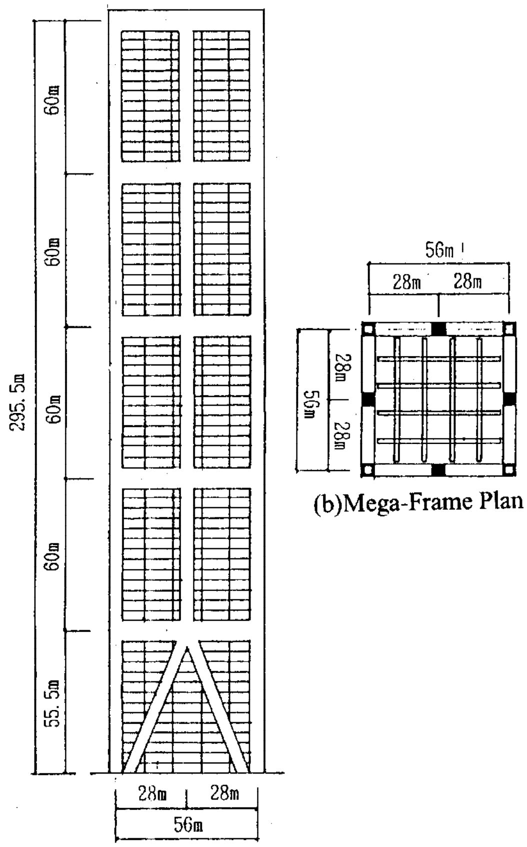


(b)Mega-Frame Plan

(a)Mega-Frame

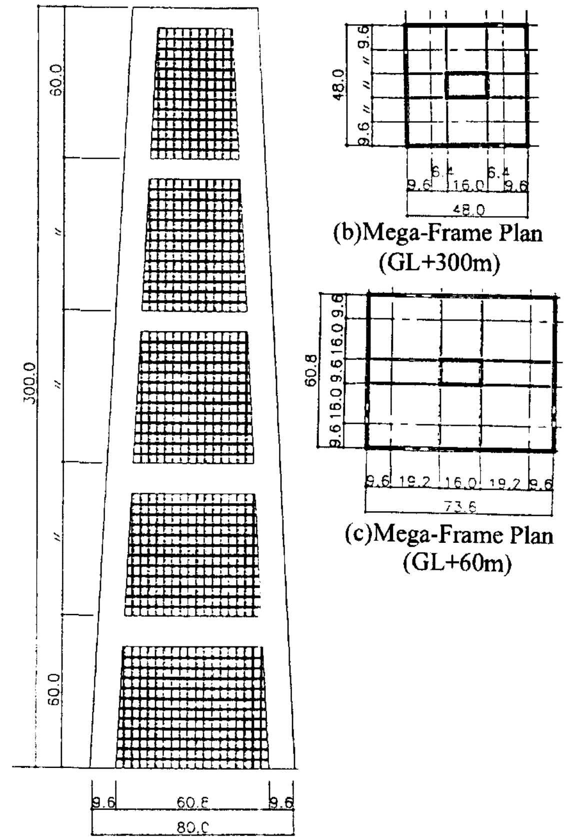
Fig.3-1 Open frame structure of 200 meters height (OP200S)



(b)Mega-Frame Plan

(a)Mega-Frame

Fig.3-2 Open frame structure with straight elevation of 300 meters height (OP300S)

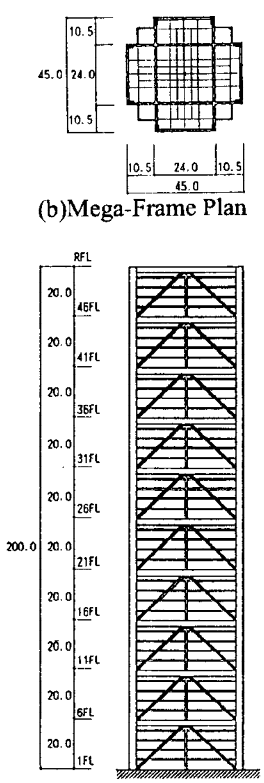


(a)Mega-Frame

(b)Mega-Frame Plan (GL+300m)

(c)Mega-Frame Plan (GL+60m)

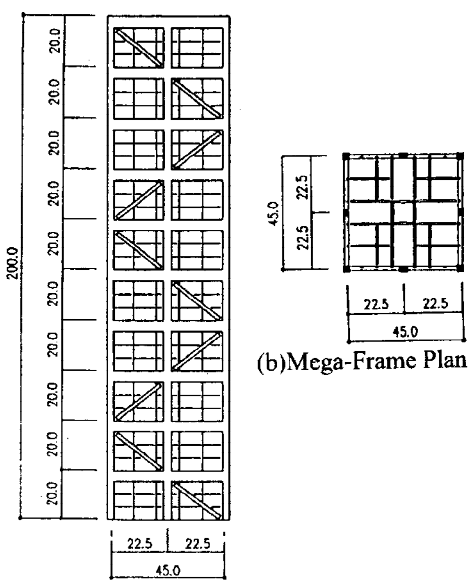
Fig.3-3 Open frame structure with tapered elevation of 300 meters height (OP300T)



(b)Mega-Frame Plan

(a)Mega-Frame

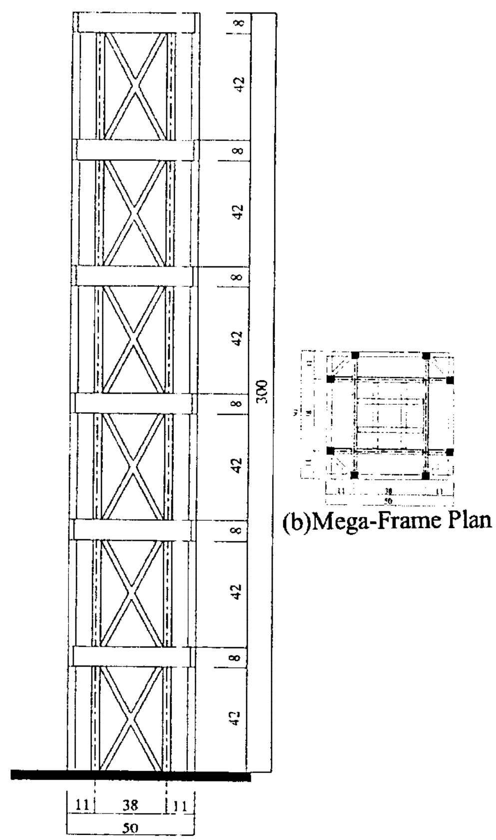
Fig.3-4 Braced frame structure using K-shaped brace of 200 meters height (BR200K)



(b)Mega-Frame Plan

(a)Mega-Frame

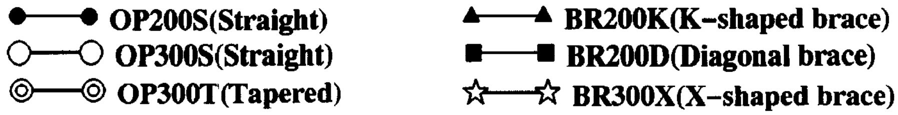
Fig.3-5 Braced frame structure using diagonal brace of 200 meters height (BR200D)



(b)Mega-Frame Plan

(a)Mega-Frame

Fig.3-6 Braced frame structure using X-shaped brace of 300 meters height (BR300X)



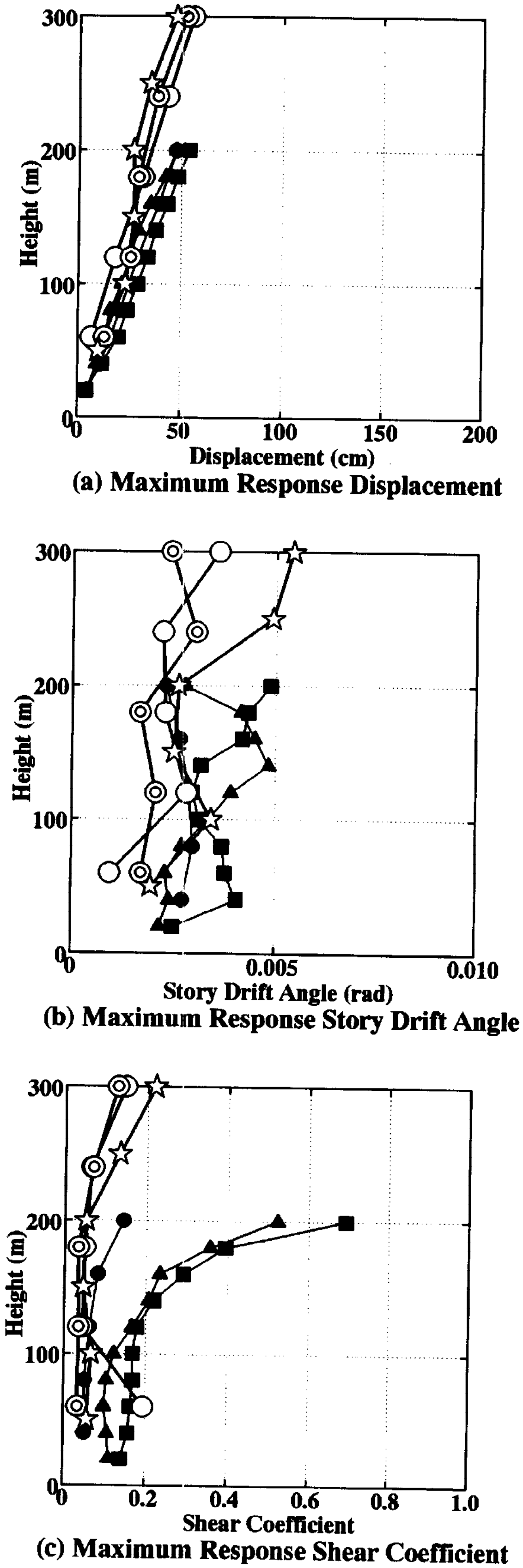


Fig.4-1 Results of dynamic response analysis
(El Centro 1940 NS)

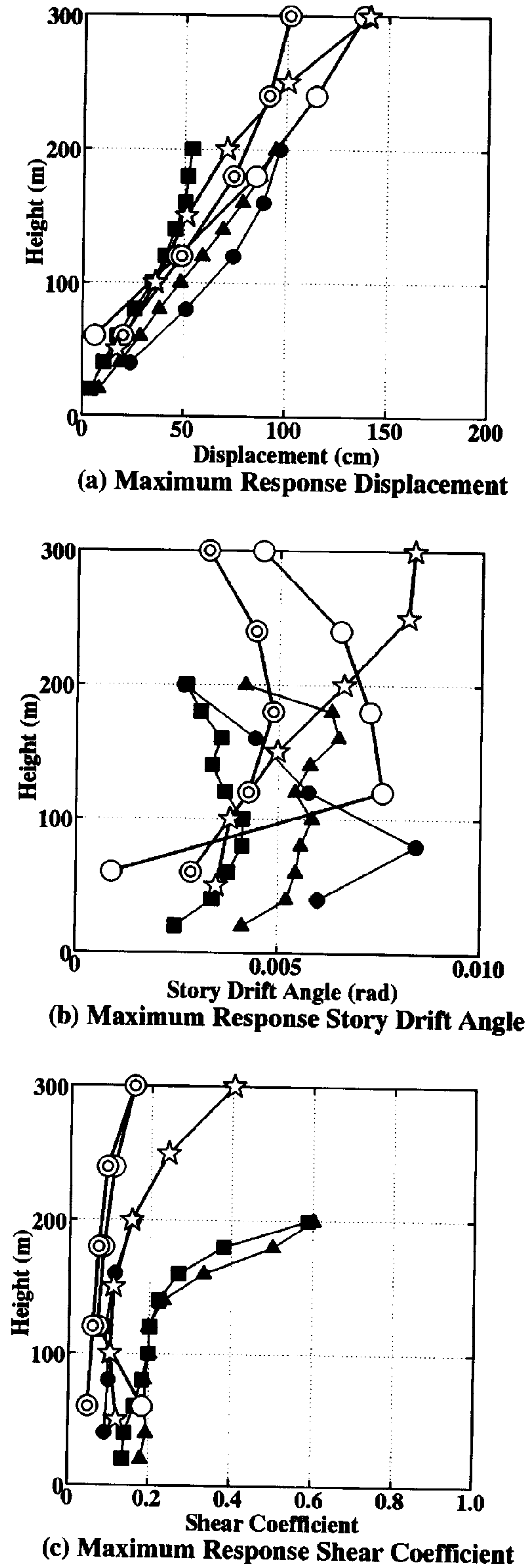


Fig.4-2 Results of dynamic response analysis
(Artificial Ground Wave of Design Spectrum)

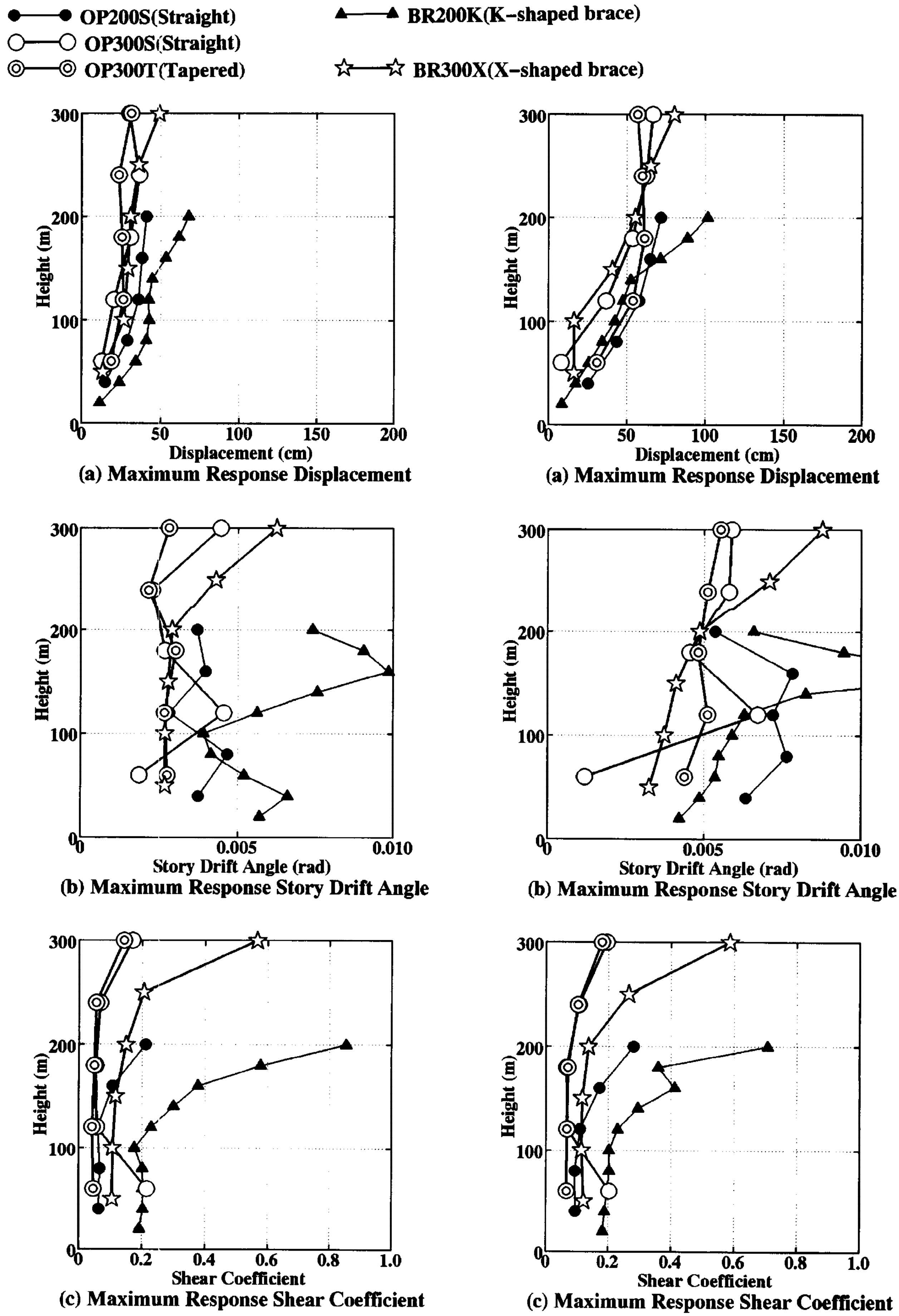


Fig.4-3 Results of dynamic response analysis (JMA-Kobe 1995 NS)

Fig.4-4 Results of dynamic response analysis (Sylmar 1994 NS)