ASEISMATIC DESIGN OF BUILDINGS IN THE REFUGE CENTER

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ABSTRACT

In Tokyo, Downtown Refuge Center Project is being carried out as part of Extensive Disaster Prevention Program projected by the Metropolitan Government. East Shirahige Refuge Center (ESRC), the construction of which is now under way, marks the first stage of the whole project which upon completion will comprise six such refuge centers. The 13-storied buildings in ESRC are planned to serve as effective barrier walls which will shield off fire and create safe evacuation space behind them. This paper describes earthquake resistant design of these buildings.

1. REFUGE CENTER PROJECTS

More than 50 years have passed since Tokyo and vicinity was hit by Kanto Earthquake which, with the fires that ensued, killed over 100-thousand people. With the population expanded to over 10 million, Tokyo-inhabitants have growing worries that the next earthquake may cause still greater casualties. In this regard, Tokyo megalopolis must find appropriate disaster prevention measures. However, the earthquake in Japan involves a number of highly complex problems and its accurate forecast still depends on further research. Thus, the disaster prevention measures are compelled to proceed on a step-by-step basis.

Priority in providing such prevention measures was given to the downtown area which is most susceptible to earthquake-caused disasters because of unfavorable soil conditions and densely built up wood houses. (In fact, it was this downtown area that suffered most disastrous damage in the Kanto Earthquake.) In line with this policy, a plan was established to provide in that area adequate refuge centers capable of ensuring the safety of inhabitants under an earthquake comparable to Kanto Earthquake which will be followed by wide-spreading fires. As a long-range plan, fireproofing of the whole downtown housing must be realized and efforts to such an end are also bearing fruit not very rapidly but gradually and steadily[1].

The refuge centers thus given the top priority has been planned in an attempt to provide earthquake-resistant and fire-resistant structures, to create the evacuation space at the center for the refugees from post-earthquake fires and to provide them with necessary medical care, food and other requisites. The structures consist of a series of 4- to 13-storied buildings which may be used as apartments under the normal condition. In case of disasters, the buildings so located as to surround the evacuation space having medical facilities will serve as continuous barrier walls against raging flame spreading from the wood houses located around the center. Therefore, fire-proofness and earthquake resistance of these buildings are paramount design considerations (Fig. 1).

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2. SEISMIC CRITERIA FOR ESRC BUILDINGS

As the first step of the project, the design of ESRC Buildings was completed which has closely been followed by the construction work. Prior to the design, thorough soil survey was conducted which included core drilling to a depth of 200 m and measurement of S-wave velocity. Based on the dynamic properties thus ascertained and the studies and analyses of the earthquake damage in the past, the earthquake intensity at ESRC site was assumed to be 300-500 gals and 40-50 kines respectively in terms of the acceleration and the velocity. By making reference to these data, the buildings' earthquake resistance was geared to Grades A, B and C (Table 1). The high-rise apartment buildings comprising barrier walls were defined to fall under Grade B.

3. HIGH-RISE APARTMENT BUILDINGS

These buildings are constructed of steel and reinforced concrete, and have 13 stories above ground and 1 basement (up to 40 m and down to 9.3 m). The superstructure is intended for dwelling and the substructure for carpark and fire fighting facilities. Especial care was paid to the fire prevention aspect: the exterior walls provided with the fire prevention shutters and the fire drencher system to prevent a spread of fire into the buildings from the outside, and the inside equipped with sprinkler system to cope with a fire occurring in the building.

In the structural aspects, the main framing is composed of large columns (2.2 m x 0.75 m in section) and small columns (0.9 m x 0.75 m), alternately located every two dwelling units apart to comprise the rigid frame structure in the longitudinal direction and the single-spanned shear wall structure in the transverse direction (Fig. 2). Since the top stratum of the ground consists of weak soil, the buildings are supported by 2.0 m diam. 30 m long cast-in-situ reinforced concrete piers. With regard to the seismic loads for design, the base shear coefficient was set at 0.5 on the basis of earthquake response analysis in the case of 40 kines. This figure is equivalent to more than two times the value required for ordinary buildings.

4. VIBRATION ANALYSES

Vibration Model: For the purpose of vibration analyses, the building was represented by a simulated model of a 13 mass system. The damping for primary period of vibration was set at 5% of the critical damping value. The restoring characteristics were considered to be linear and tri-linear types. Natural vibration period of the building measured 0.59 and 0.20 seconds respectively for the primary and the secondary periods in the longitudinal direction and in the same way 0.43 and 0.12 seconds in the transverse direction.

Earthquake Waves for Analyses: Three types of strong earthquake motion previously recorded and an artificial earthquake wave adopted with due consideration to the soil characteristics of the site were used. Maximum acceleration and other related features of these recorded earthquakes are shown in Table 2. By making reference to the maximum velocity therein shown, the intensity of earthquake was assumed 40, 60 and 80 kines.

Elastic Response Analyses: The elastic response analyses in the case of 40 kines are as shown in Fig. 3. As can be seen from those results, the maximum base shear coefficients were in a range of 0.34 to 0.43 which was obviously below the required design value of 0.5. Therefore, in the building, no appreciable cracking would be produced and the framing would, for the most part, be in the elastic range.

Elasto-Plastic Response Analyses: According to the response analyses for 60 kines, the ductility factor did not exceed 2.0. The ratios of story deflection to story height were 1/190 in the longitudinal direction and 1/400 in the transverse direction. Then, cracking which may be caused in the building due to earthquake is considered structurally negligible. In the case of 80 kines, the ductility factor and the story deflection-height ratio were 2.5 and 1/127 in the longitudinal direction and 3.8 and 1/200 in the transverse direction respectively (Fig. 4).

Building-Pier-Soil Interaction Response Analyses: A vibration model was adopted that was arranged to reflect combined behaviors of building, piers, the soil surrounding the piers and the undisturbed soil[2] (Fig. 5). The primary natural periods of vibration were 0.56 seconds solely for the superstructure, 0.74 seconds for the soil and 0.87 seconds for the entire interaction system. As earthquake wave input, artificial underground wave at 36 meters below the ground surface was adopted and so arranged as to produce at the surface the velocity of 40 kines. These response analyses results are shown in Fig. 6. The maximum base shear coefficient was 0.35, thus clearly reflecting the favorable effect of building-pier-soil interaction. The maximum shear force in the pier roughly equaled the static stress caused when the design shear force on the 1st floor was applied on the butt of piers.

5. CONCLUSION

The present studies were made in order to establish the criteria for earthquake resistance required for the working design of the ESRC project. In the future, these study results should be ascertained and made more reliable and comprehensive by utilizing the results of vibration tests on building and piers to be conducted during the construction as well as by earthquake observation at the buildings during and after construction. The resulting information will be a helpful guideline for planning the ensuing refuge center projects.

REFERENCES

1) HAJIME UMEMURA "How to Prevent Earthquake Disasters in Tokyo," *Some Recent Earthquake Engineering Research and Practice in Japan* (The Japanese National Committee of the International Association for Earthquake Engineering, May 1973) pp. 165-176 (Reported at the fifth WCEE)

2) JUNYA IMAMURA et al., "Building-Soil Interaction Analysis by Equivalent Mass-Spring System," *Transactions of Japan Earthquake Engineering Symposium 1973 in Commemoration of the 50th Anniversary of the Kwanto Earthquake.*

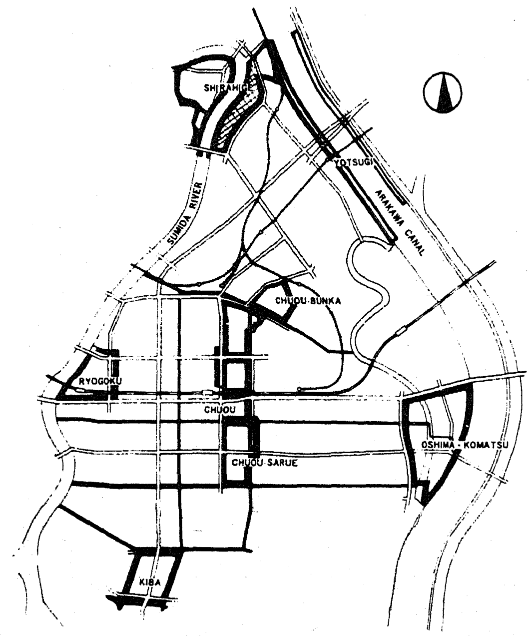


FIG. 1 Planned Array of Refuge Centers

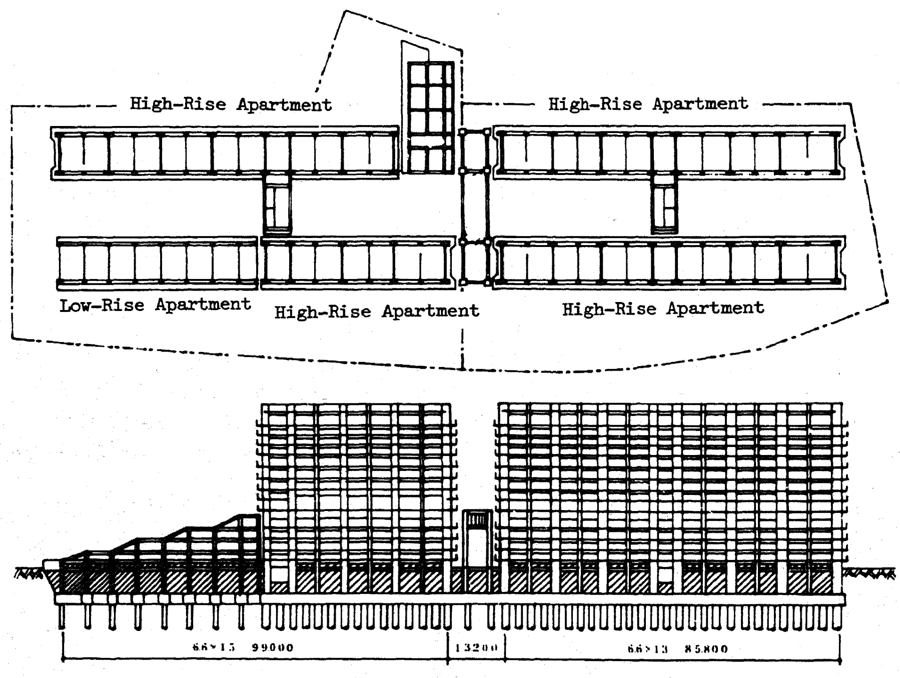
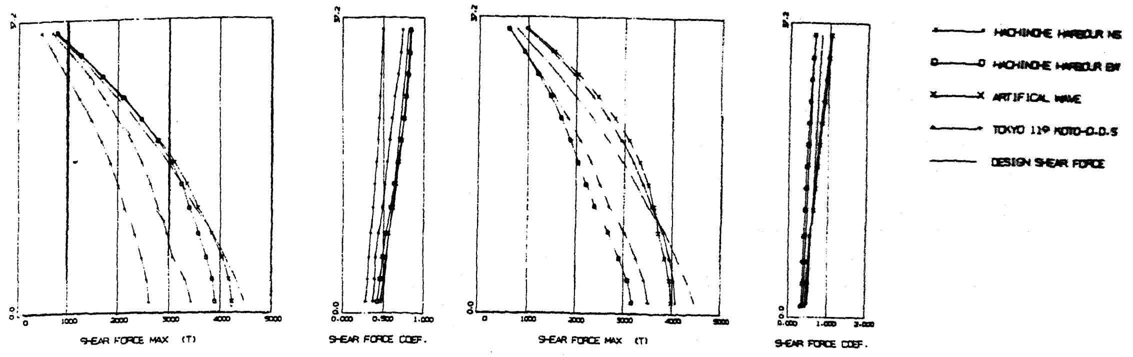
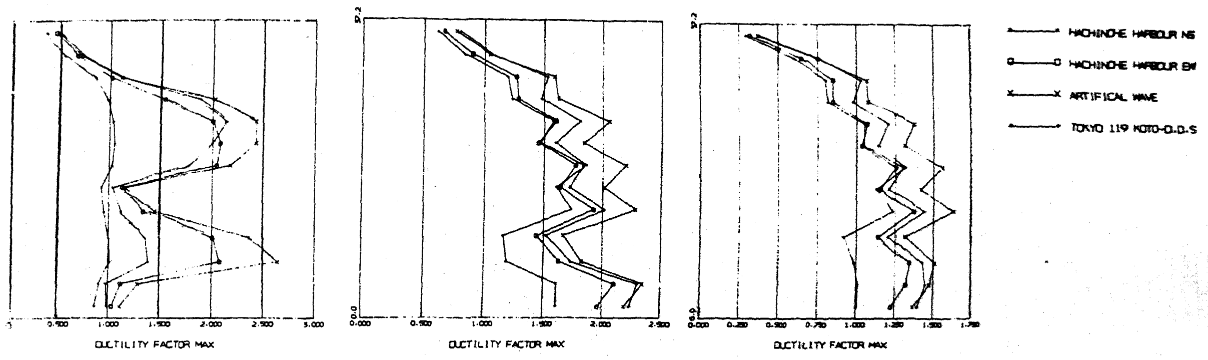


FIG. 2 ESRC Apartment Building - Plan and Elevation



Transverse Direction　　　　Longitudinal Direction

FIG. 3　Elastic Response Analyses (40 kines)



Longitudinal Direction　　Transverse Direction (Primary Shear Wall)　　Transverse Direction (Secondary Shear Wall)

FIG. 4　Elasto-Plastic Response Analyses (80 kines)

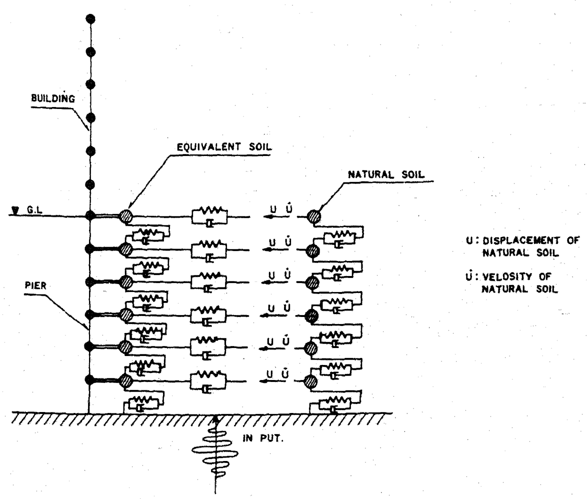


FIG. 5　Building-Pier-Soil Interaction Model

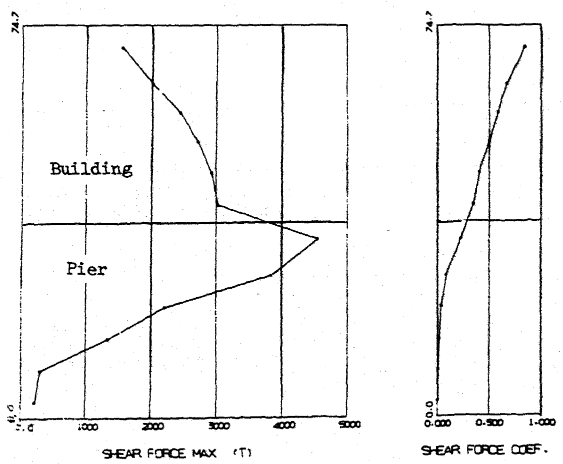


FIG. 6　Max. Values of Building-Pier-Soil Interaction Response (40 kines)

Table 1 Seismic Criteria for ESRC Project

Earthquake intensity	Response Conditions of Buildings for Ground Motion			Buildings as classified for ESRC Project
	250 gals or 40 kines	400 gals or 60 kines	500 gals or 80 kines	
Grade A	Elastic	*Condition I* Elastic for the most part	*Condition II* Ductility factor of not more than 2	Buildings constituting indispensable parts of Refuge Center
Grade B	*Condition I* Elastic for the most part	*Condition II* Ductility factor of not more than 2	*Condition III* Buildings will not collapse.	Buildings important for the purpose of Refuge Center, including high-rise apartment bldgs. and storages for emergency supply
Grade C	*Condition II* Ductility factor of not more than 2	*Condition III* Buildings will not collapse.		Buildings independent of the purpose of Refuge Center, including shops, workshops.

Table 2 Earthquake Waves Used

Earthquake waves as named	Direction	Date	Intensity as originally recorded		Acceleration in case of 40 kines	Names of Earthquake
			Max. Acceleration	Max. Velocity		
HACHINOHE HARBOR	NS	May 16, 1968	225 gals	31.5 kines	286 glas	"Tokachi-Oki" Earthquake
ditto	EW	ditto	183	34.1	215	ditto
TOKYO 119 KOTO DDS	NS	July 1, 1968	49.6	9.44	210	"East Matsuyama" Earthquake
NEW-SBK-HAC					317	Artificial earthquake wave

N.B. The maximum response velocity of one mass system with a natural period T = 10.0 seconds and a damping h^2= 0.5 was taken as the maximum velocity.