Paper No. 835. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

THE RESTORATION OF THE IKUTA SHRINE DESTROYED BY THE GREAT HANSHIN EARTHQUAKE USING ULTRA HIGH STRENGTH COMPOSITE COLUMN

TOSHIHARU HISATOKU[1], TERUO SEGAWA[2], TATSUO OKAMOTO[2]
1)Takenaka Corporation, 8-21-1, Ginza, Chuo-ku, Tokyo, Japan
2)Structural Engineering Section, Building Design Department, Takenaka Corporation, 2-3-10, Nishi Hom-machi, Nishi-ku, Osaka, Japan

ABSTRACT

The Great Hanshin Earthquake (The 1995 Hyogoken-Nanbu Earthquake) attacked Kobe on January 17, 1995 and brought us the huge destruction. The IKUTA shrine in which Wakahirume-no-mikoto, the infant princess of Japanese mythology, is worshipped, could not also escape from the violent hands of the natural disaster. A lot of buildings were damaged and the Hall of Worship fell down completely. In the ruins, the superior priest of the shrine requested us to restore the buildings as soon as possible to encourage citizens of Kobe. Then re-construction of the shrine started on January 22, 1995. The progressive technology to give the buildings sufficient seismic resistant capability is intended to serve in honor of the mythological princess. For the columns of the new Hall of Worship, CFT(Concrete Filled steel Tube) is used, and the concrete which compressive strength is 1,600kgf/cm^2, is filled into the tube. The restoration procedure of the new Hall will be reported.

KEYWORDS

The Great Hanshin Earthquake; IKUTA shrine; Hall of Worship; CFT; Cantilever; Ultra High Strength Concrete; 1,600kgf/cm^2; Simulated Ground Motion; Seismic Response Analysis

INTRODUCTION

Statistics of Building Damage by The Great Hanshin Earthquake

The 1995 Hyogoken-Nanbu Earthquake that occured at 5:46 AM local time on January 17, 1995 caused devastating damage to Hanshin Area. The earthquake magnitude is estimated 7.2 by JMA(Japan Meteorogical Agency) and the epicenter or the origin of the fault fractured is assumed at the north end of the Awaji Island, 15km deep and 20 km apart from Kobe City. The strip area at the foot of Rokko Mountain, 20km length and 1km width, from Kobe through Ashiya to Nishinomiya was severely damaged and the Japanese intensity scale of earthquake VII was recorded to these area for the first time in Japan. The earthquake killed more than 6,000 people and destroyed more than 90,000 houses completely.

In the investigation of damaged buildings by earthquakes, the following damage index is used to describe the building by Architectural Institute of Japan(1995).

Collapse	Failure or overturning of the entire structure or complete failure of a single story
Severe damage	A large portion of building frame is damaged, permanent deformation of the structure may cause imminent collapse
Moderate damage	Significant structural damage is visible. Permanent deformation between stories exists but with low possibility of collapse
Minor damage	Minor structural damage, although the structure may have significant architectural damage
Slight damage	No structural damage. Architectural damage may be noticieable

The earthquake damage statistics by Architectural Institute of Japan, Kinki Branch(1995) is shown in Table 1(a). 4,826 buildings were investigated and it was reported that number of collapsed or severely damaged RC,SRC buildings was 591(22%of surveyed RC,SRC buildings). Kobe is birthplace of Takenaka Corporation and many buildings had been designed and/or constructed in Hanshin area by Takenaka. Table 1(b) gives damaged building number constructed by Takenaka. Takenaka (1995) reported that among 1,725 buildings investigated, 42 buildings were collapsed or severely damaged.

The damage ratio, number of collapsed and severely damaged buildings to the investigated buildings, was 2.4% in the buildings constructed by Takenaka. The building codes and regulations for seismic design had been improved in 1970 and in 1980. The damage ratio of Takenaka works was 3.7% for the buildings designed before 1970 and 2.6% for the buildings designed between 1971 and 1980 while 0.6% for the buildings after 1981. It should be noted that the damage ratio was reduced remarkably as the design codes were strengthened.

Table 1. Number of damaged buildings

(a) Number of damaged buildings investigated by A.I.J.

	collapse	severe damage	moderate damage	minor damage	total
RC,SRC	254	337	346	663	1600
S	162	294	328	476	1260
total	416	631	674	1139	2860

4,826 buildings investigated

(b) Number of damaged buildings constructed by Takenaka Corpcration

	collapse	severe damage	moderate damage	minor damage	total
RC,SRC	15	22	44	660	741
S	2	3	8	90	103
total	17	25	52	750	844

1,725 buildings investigated

According to the policies, the details of the structural design are determined as follows ;

(1) The columns of the Hall are fixed to the foundation and support the roof load vertically and horizontaly as the cantilever from the foundation.

(2) The building should be in the elastic range when the acceleration 980 cm/sec^2 is exercised to the structure not only in the horizontal direction but also in the vertical direction simultaneously during earthquake.

(3) The building should withstand when the earthquake such as The Great Hanshin Earthquake attacked the IKUTA Shrine again.

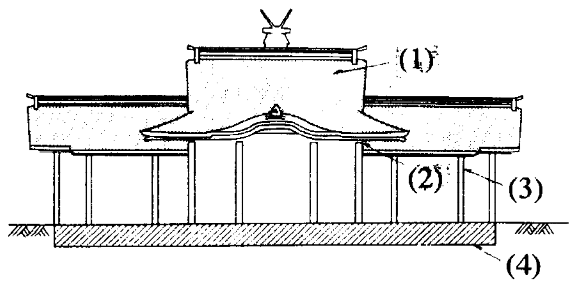
(4) Concrete Filled steel Tube(CFT) is used for the column of the hall.

(5) Ultra high strength concrete, which compressive strength is 1,600kgf/cm^2, is used for the CFT.

(6) Cast steel is used for the *Daito* , which is one of the traditional connecting element between column and girder.

(7) The gracefuly curved roof made of wood is strengthened by using the steel connecting plates and bolts.

The outline of the structure is given in Fig. 1. The CFT columns are connected to the steel encased reignforced concrete foundation supported by prestressed concrete piles. Fig.2 shows the structural elements of the hall. Wooden connecting members are situated on the *Daito* on top of the CFT column. The said members are fixed by using long steel bolt from girder to column in order to securely fasten all the elements.



(1) Wooden roof structure
(2) *Daito* (cast steel)
(3) CFT column(high strength concrete filled) fixed to the foundation
(4)Steel encased reignforced concrete foundation

Fig.1 The Outline of The Structure

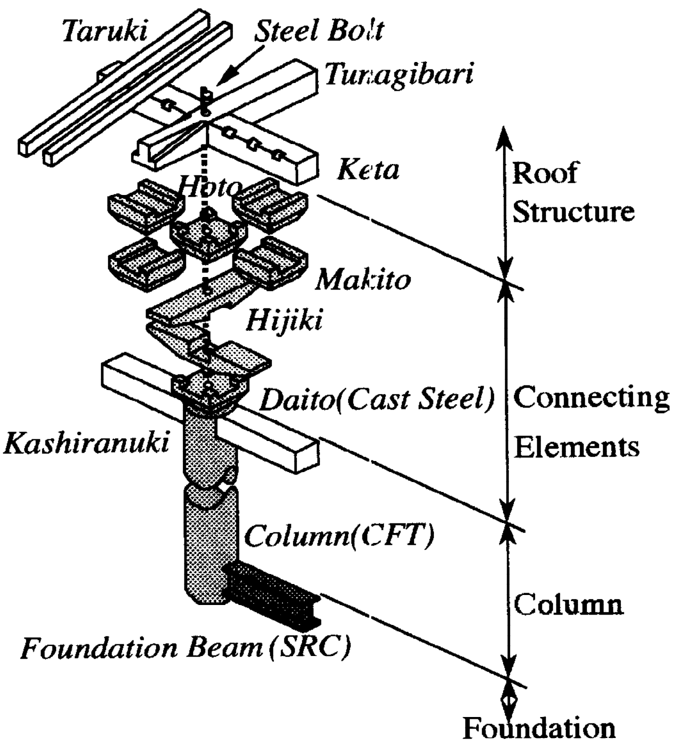


Fig.2 Structural Elements of The New Hall

Load Bearig Capacity of The CFT Column Used For The Hall

Concrete filled steel tube is used for the columns of the new Hall. Diameters of the steel tube are 355.6mm and 267.4mm and the thickness are 11.1mm and 9.3mm respectively. The used steel tube is STK400 prescribed in JIS (Japan Industrial Standard) which ultimate strength is 41kgf/mm^2. The compressive strength of the filled concrete in the tube is 1,600kgf/cm^2 . The concrete is cast by using centrifugal compaction and cured by autoclaved method.

Experimental Result of Compressive Strength The compression test of the CFT was executed. In the test, STK400 steel tube is used for the specimens and the diameter of the specimen is 101.6mm and the length is 304.8mm. Mix proportion of the filled concrete and its compressive strength is given in Table 2. The yield strength of the steel is 43.5 - 48.0 kgf/mm^2 and ultimate one is 50.7 - 53.3 kgf/mm^2.

Table 2. Mix proportion of the filled concrete and its compressive strength

mix proportion (kgf/m^3)						Comp. Strength
water	cement	sand	aggregate	silica fume	plasticizer	(kgf/cm^2)
120	500	654	1003	150	35	1342

Comparison of the experimental value of the maximum compressive force to the simply superposed compressive strength is indicated in Table 3, and the comparison to the strength estimated by the proposed equation for the high strength concrete by Okamoto et al.(1995) is also shown in Table 3. The experimental compressive strength exceeds the superposed strength, and coincides with the estimated strength by Okamoto et al.(1995).

Table 3. Comparison of experimental compressive strength to calculated value

Specimen	Max. Comp. Force Pmax(tf)	Pmax/P(superposed)	Pmax/P(Okamoto)
Φ101.6x3.2	195	1.12	1.02
Φ101.6x4.2	218	1.19	1.06
Φ101.6x5.7	232	1.17	0.99

Experimental Result of Beam Column Test The beam column test was also executed for the CFT. The experimental model is designed as about 1/3 of real columns of the Hall of Worship. The used steel tube is STK400 and its size is Φ101.6x3.2 with the length of 1,016mm. Filled concrete is the same as the compression test. The axial force ratio to the superposed compressive strength is 0.05 which is almost the same as the real column.The horizontal load is applied cyclicly at the top of the specimen as the specimen behaves as the cantilever. The moment - rotation relation is given in Fig.3. The hysteresis curve shows sufficient flexural ductility and the ultimate bending moment is 2.13tfm which exceeds the estimated value 1.73tfm in the structural design following the Architectural Institute of Japan(1987) code.

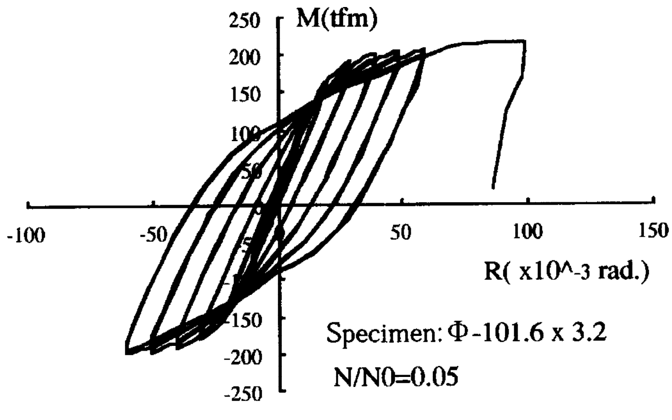


Fig.3 Moment - Rotation relation

SEISMIC RESPONSE ANALYSIS OF THE NEW HALL

To certify the new Hall not to be severely damaged by such earthquake as The Great Hanshin Earthquake, we executed the seismic response analysis of the new Hall using the artificial ground motion generated from the recorded accelerogram at the other place.

Simulated Ground Motion at The IKUTA Shrine

Since there was no recorded accelerogram of The Great Hanshin Earthquake at the IKUTA shrine, the ground motion for the analysis is generated by wave propagation analysis technique as sketched conceptually in Fig.4 . The acceleration and velocity data observed in this earthquake in Kobe area indicate that the dominant ground motions occur simultaneously in the vertical direction and in the horizontal direction and phase properties agree well in both directions. This feature implies that the dominant motion in the vertical direction was simulated by SV propagation.
One of the two horizontal components and vertical component of the ground motion at the IKUTA shrine are generated, therefore, by SV wave propagation analysis and another horizontal component is simulated by SH wave propagation analysis. The bedrock motion is calculated by deconvolution of the accelerogram data recorded at Kobe University 6km northeast from the shrine.The generated bedrock motion at Kobe University 250m below ground is input at the bedrock of the IKUTA shrine 400m below the ground. Shear velocities(Vs) are assumed to be 3,200m/s in the bedrock, 1,000m/s in the soil deposit at Kobe University and 1,000m/s to 115m/s in the soil strata at the IKUTA Shrine. Simulated ground motion at the IKUTA Shrine is given in Fig.5. Maximum horizontal acceleration is 665.3 (gal) in EW, and the peak value of horizontal and vertical motion occurs simultaneously.

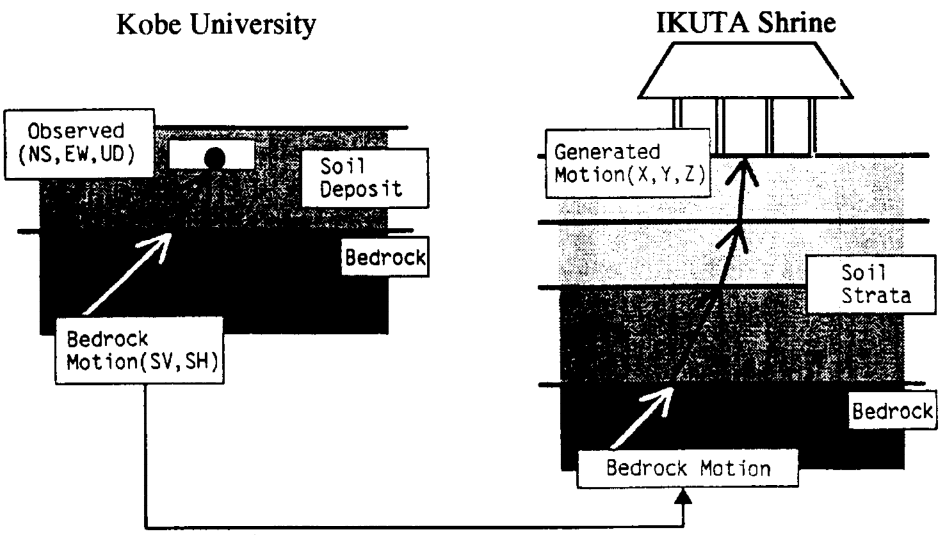


Fig.4 Conceptual illustration of deconvolution / convolution analysis

Seisimic Response Analysis

Elasto-plastic seismic response analysis is done using the simulated ground motion. Structural model is given in Fig.6. The whole roof is integrated to simple one mass and the columns of the hall are also integrated to one

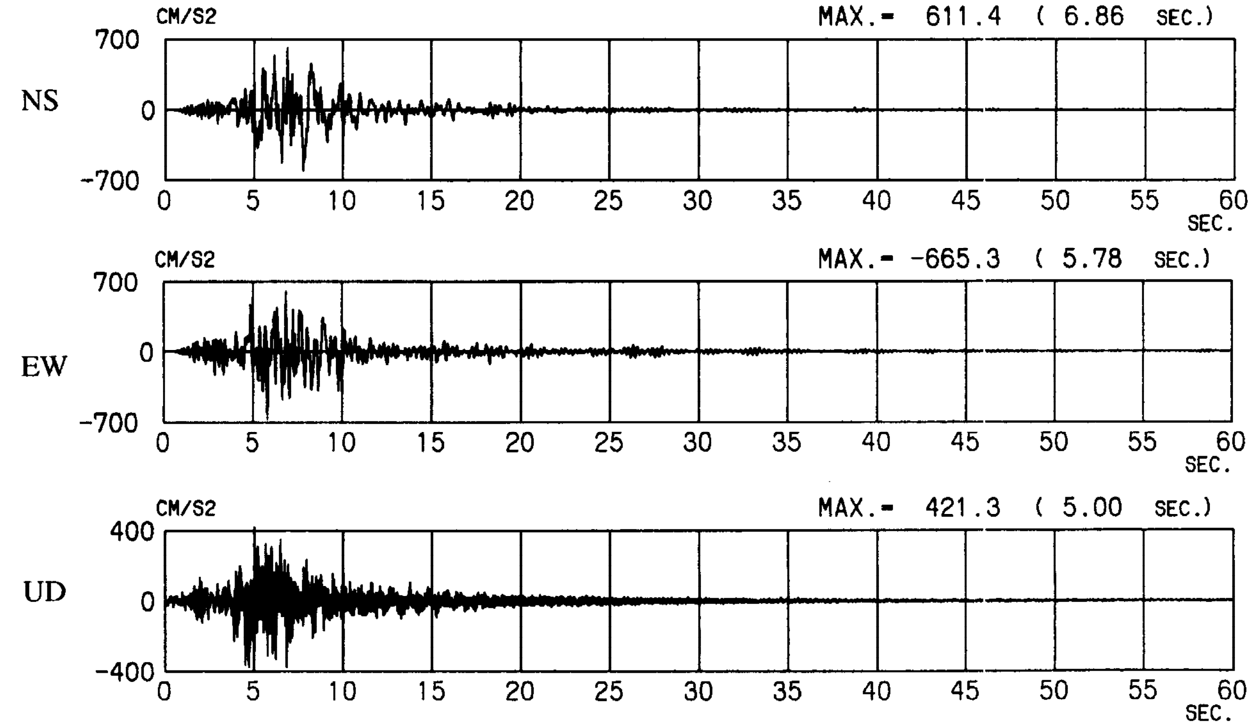


Fig.5 Simulated ground motion at the IKUTA Shrine

lateral spring. We use the normal Tri-linear skeleton curve for the analysis. Fig.6 shows the skeleton curve for the analysis. The shear forces corresponding to the full plastic moment of each column are indicated in it. Table. 4 shows the result of the response analysis. The analytical result shows that the shear force working in the CFT column is relatively small, and it is below the ultimate value. Therefore, the structure will be safe when attacked by the same earthquake as The Great Hanshin Earthquake.

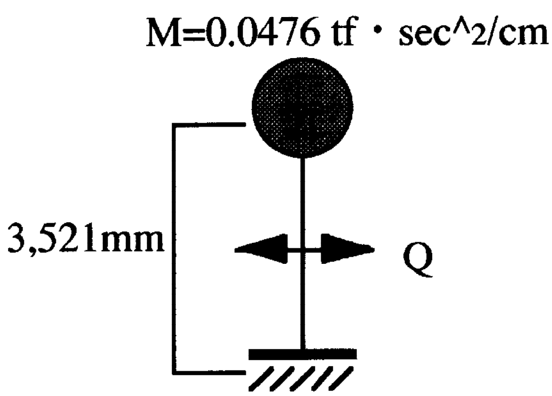


Fig.6 Structural model for response analysis

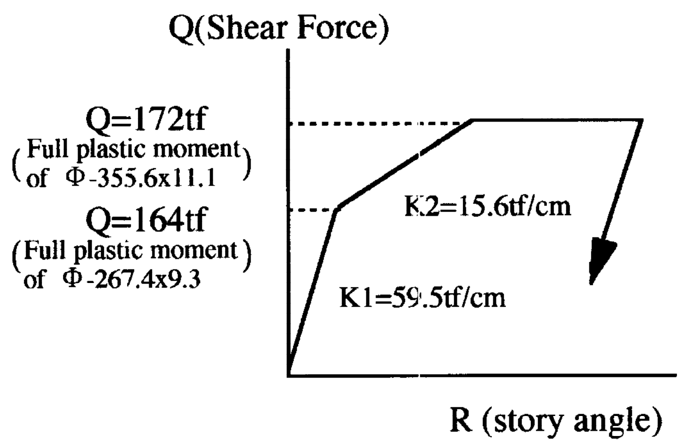


Fig. 7 Normal tri-linear skeleton curve

Table 4. Result of the response analysis

	Acceleration (gal)	Displacement (cm)	Shear force (tf)
NS Direction	1232	0.98	58.8
EW Direction	1517	1.21	72.3