Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.V)

7-7-4

# DESIGN OF A TUBED-TWIN TOWER WITH CONNECTING BEAMS

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SUMMARY

A tubed twin-tower building with connecting beams was designed and is under construction in Tokyo, Japan. this paper presents how the design procedure was performed and the final decision of the scheme was reached, especially concerning to its connection method and its seismic behavior.

## INTRODUCTION

General Each tower consists of 20 stories used for offices and 2 basements. They have almost the same L-shape plan respectively, and are located symetrically to the central point. The space between two towers is used for an atrium with a glass roof and it is void up to the top(Fig. 1,2.).

The outline of the project, the structure and the materials used are shown in Table 1.

Design Philosophy and Structural Features One of the main structural characteristics of this building is that the towers are connected by beams to

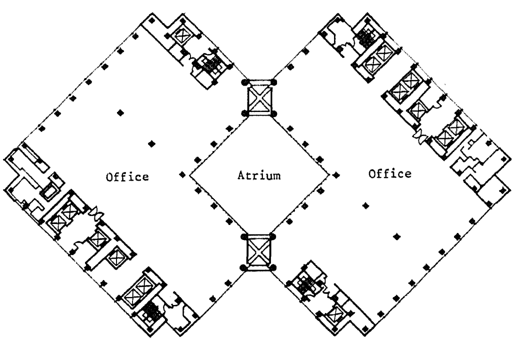



Fig.1 Typical Floor Plan

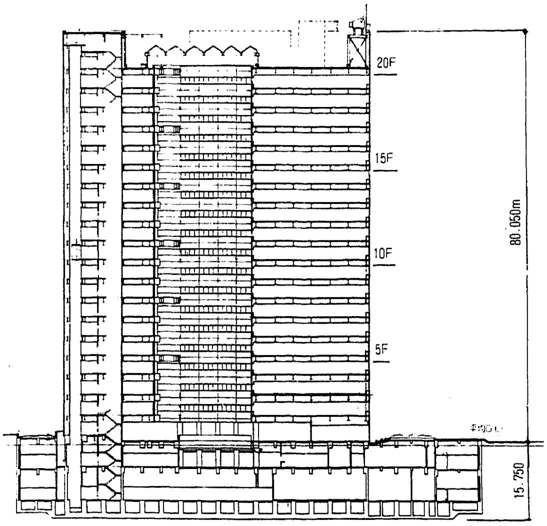



Fig.2 Section

Table 1 Project and Structure Outline

| | |
|---|---|
| Name of Project | Shin-Nikko Building |
| Owner | Nippon Mining Co., Ltd. |
| Location | Toranomon, Minato-ku, Tokyo, Japan |
| Use | Office |
| Site Area | 9,840 $m^2$ |
| Total Floor Area | 66,800 $m^2$ |
| Building Area | 3,200 $m^2$ |
| Story | 20 Stories, 2 Basements |
| Height | Eave Height 79.27 m, Max. Height 80.05 m |
| Exterior Walls | 2Fl-Top Glass and Aluminum Curtain Walls<br>1Fl-2Fl Precast Concrete Panels |
| Foundation | Direct Foundation |
| Frame | Under 1Fl SRC(Steel Reinforced Concrete) and RC(Reinforced Concrete) Structure<br>1Fl-Top S(Steel) Structure |
| Aseismic System | Multi-story Steel Braces<br>Tubed Structure with Peripheral Frames |
| Used Material | (JIS)<br>Steel : SM53, SM50, SS41<br>Heigh Strength Bolt : F10T, M22, M20, M16<br>Reinforcing Bars : SD30, SD35<br>Concrete : Normal Fc=240kg/$cm^2$ $\gamma$=2.3<br>: Light-weight Fc=210kg/$cm^2$ $\gamma$=1,7 |

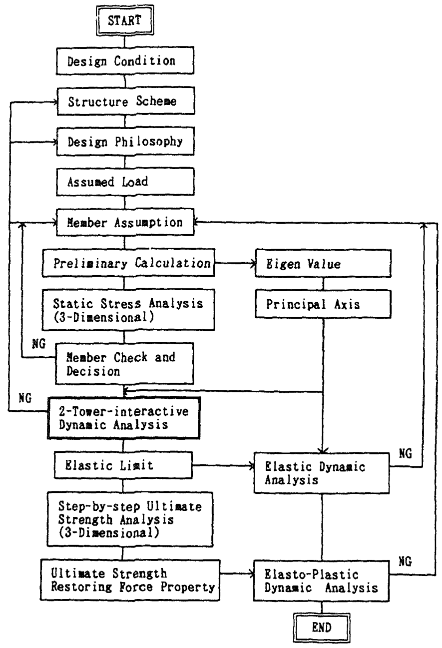



Fig.3 Structural Design Flow Chart

have a uniform horizontal movement. If the towers moved independently under a severe earthquake, the relative desplacement between them at the connecting part would be over 100 cm. In the other hand the glass roof and the glass curtain walls should be installed at the top of the atrium and the slits between the towers, respectively. So, its impossible to design such roof and curtain walls safely without the connecting beams.

The L-shape plan of the towers causes a torsional movement under seismic loadings. So, by connecting the towers the torsional unstability was reduced, thus an economical advantage on the building design was obtained

Selected connections at one connection part after our examination are:

i) One external beam at each floor
ii) Two(internal and external) beams and two horizontal braces between them at every three floors.
iii) the section of the beams, and braces is H-800x375x19x28.

Other structural features are as follows:

i) Tubed structure consists of the peripheral 3.6m-span frames
ii) 14.4m and 14.8m span spaces without column for the offices

Design Flow Chart Fig.3 shows the whole structural design flow chart. In Japan, when the height of the building is greater than 45m, a dynamic analysis shall be performed for safety against earthquakes. As this building consists of two towers, a 2-tower-interacive dynamic analysis was performed and the connection was examined as will be explained in the following sections.

In the static stress analysis, a 3-dimensional model assuming the floors located at the same height as one rigid floor, was used. This assumption was confirmed by the 2-tower-interactive dynamic analysis.

This 3-dimensional stress analysis was performed for:

i) Modelling the connecting beams, that are not in X or Y directions, properly.
ii) The plan of this building has a complicated shape as shown in Fig.4.

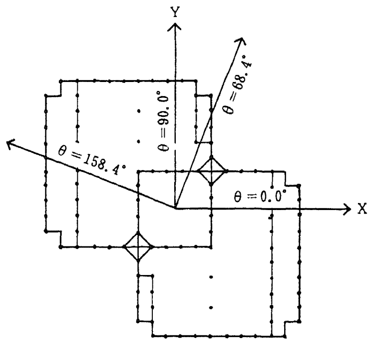



Fig 4 Principal Axis

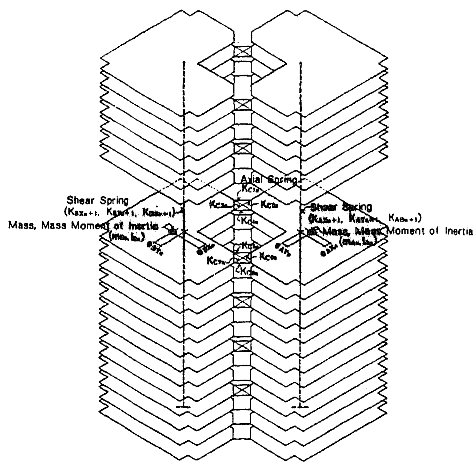



Fig.5 Model

Table 2 Structural Properties of the Towers

| Floor | Tower-A | | | | | | | Tower-B | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | W (ton) | $10^{-4}I_g$ ($tm^2$) | $K_x$ (t/cm) | $K_y$ (t/cm) | $10^{-4}K_t$ (tm/rad) | $e_x$ (m) | $e_y$ (m) | W (ton) | $10^{-4}I_g$ ($tm^2$) | $K_x$ (t/cm) | $K_y$ (t/cm) | $10^{-4}K_t$ (tm/rad) | $e_x$ (m) | $e_y$ (m) |
| R | 452.5 | 14.7 | 90.1 | 151.9 | 342.6 | 1.06 | 0.29 | 452.5 | 14.7 | 90.1 | 151.2 | 342.5 | -1.07 | -0.29 |
| 20 | 1536.8 | 42.9 | 693.9 | 814.6 | 2659.1 | -1.56 | 1.07 | 1536.6 | 42.9 | 694.1 | 814.7 | 2659.4 | 1.56 | -1.07 |
| 19 | 778.2 | 23.1 | 821.2 | 905.7 | 3001.1 | -1.06 | 0.67 | 772.3 | 23.2 | 821.2 | 906.0 | 3001.1 | 1.14 | -0.64 |
| 18 | 780.6 | 23.2 | 907.5 | 969.6 | 3260.6 | -1.42 | 1.12 | 784.6 | 23.3 | 907.8 | 969.5 | 3260.5 | 1.49 | -1.09 |
| 17 | 791.4 | 23.5 | 975.8 | 1017.3 | 3443.3 | -1.57 | 1.27 | 795.3 | 23.6 | 975.9 | 1017.2 | 3443.2 | 1.64 | -1.24 |
| 16 | 792.2 | 23.5 | 1019.4 | 1036.4 | 3530.2 | -1.28 | 1.03 | 796.1 | 23.6 | 1019.6 | 1036.3 | 3530.2 | 1.35 | -1.00 |
| 15 | 792.2 | 23.5 | 1065.7 | 1077.1 | 3698.8 | -1.55 | 1.36 | 796.1 | 23.6 | 1072.9 | 1077.1 | 3701.8 | 1.62 | -1.37 |
| 14 | 799.7 | 23.8 | 1129.0 | 1118.8 | 3880.0 | -1.52 | 1.39 | 803.3 | 23.8 | 1129.2 | 1118.8 | 3880.0 | 1.59 | -1.36 |
| 13 | 811.3 | 24.1 | 1159.2 | 1127.9 | 3925.4 | -1.39 | 1.15 | 815.1 | 24.1 | 1159.2 | 1127.9 | 3925.5 | 1.46 | -1.12 |
| 12 | 802.6 | 23.9 | 1208.3 | 1163.7 | 4071.9 | -1.57 | 1.46 | 806.5 | 23.9 | 1208.3 | 1163.7 | 4071.7 | 1.64 | -1.42 |
| 11 | 805.5 | 24.0 | 1278.0 | 1222.1 | 4310.5 | -1.43 | 1.48 | 809.4 | 24.1 | 1278.0 | 1221.9 | 4310.1 | 1.50 | -1.45 |
| 10 | 813.1 | 24.3 | 1310.1 | 1232.5 | 4357.6 | -1.21 | 1.17 | 816.8 | 24.3 | 1310.2 | 1232.6 | 4358.1 | 1.28 | -1.14 |
| 9 | 813.1 | 24.3 | 1372.0 | 1286.9 | 4553.7 | -1.56 | 1.46 | 816.8 | 24.3 | 1372.1 | 1286.9 | 4553.9 | 1.63 | -1.43 |
| 8 | 818.6 | 24.5 | 1445.2 | 1412.8 | 4817.4 | -0.28 | 1.55 | 822.7 | 24.6 | 1445.4 | 1412.9 | 4818.1 | 0.34 | -1.54 |
| 7 | 832.6 | 24.9 | 1494.4 | 1442.2 | 4917.4 | -0.14 | 1.28 | 837.1 | 25.0 | 1494.6 | 1442.2 | 4918.0 | 0.18 | -1.25 |
| 6 | 832.6 | 24.9 | 1584.9 | 1497.2 | 5161.3 | -0.53 | 1.51 | 837.0 | 25.0 | 1585.1 | 1497.6 | 5162.7 | 0.57 | -1.49 |
| 5 | 837.3 | 25.1 | 1713.6 | 1588.7 | 5575.8 | -0.40 | 1.58 | 841.9 | 25.2 | 1713.8 | 1587.8 | 5573.0 | 0.43 | -1.56 |
| 4 | 849.5 | 25.6 | 1719.6 | 1550.9 | 5272.4 | 0.48 | 1.38 | 853.2 | 25.7 | 1719.9 | 1561.1 | 5309.4 | -0.26 | -1.30 |
| 3 | 921.4 | 27.6 | 1878.3 | 1741.9 | 5765.0 | 1.19 | 1.46 | 922.1 | 27.6 | 1878.2 | 1521.9 | 5806.2 | -1.06 | -1.46 |
| 2 | 985.9 | 30.2 | 1900.2 | 1848.9 | 6042.8 | 0.74 | 1.45 | 993.1 | 30.5 | 1900.4 | 1848.0 | 6040.0 | -0.54 | -1.27 |

## EXAMINATION OF THE CONNECTING TYPES

Analysis The basic vibrational model(Model-1) is a 120-degree-of-freedom model which consists of 2 towers of 20 masses each with connecting springs and shear springs, as shown in Fig.5. Each floor of the tower is assumed to be rigid. The masses are located at the center of each mass and the equivalent shear springs, which represent X,Y directions and rotation in each plane of the floor, are attached at rhe center of stiffness. Table 2 shows the structural properties for the model. Natural periods are 2.09sec (torsional) and 2.05sec, 2.00sec (principal axes).

A numerical integration response analysis by linear acceleration method was performed using actual earthquake records. Calculating time step is 0.01sec, duration time is 20sec and internal viscous damping ratio is 0.02.

EL CENTRO NS and EW are used at the same time as earthquake motions, and the maximum acceleration is decided such that the maximum estimated velocity is 25cm/sec(Table 3). The velocity is estimated as follows:

i) Perfoming response analysis with 1-degree-of freedom model with a first natural period equal to 10.0sec and a 0.707 damping ratio and the NS and EW records.

ii) Taking the composition of the response velocities of the two directions at each time step.

Four incident directions under consideration are shown in Fig.4. In case of $\theta=0°$ in Fig.4, EL CENTRO NS input from $0°$ direction and EW input from $(0°+90°)$ direction. Incident time lag between the two towers were also examined and were compared with the case without it. The time lag was decided as 0.08sec which is equal to the distance between the two mass centers of each tower divided by the S-wave velocity of the base layer.

Table 3 Maximum Accelerations of Actual Record and Used in Anayses

| *Earthquake* Record | *Direction* | *Max. Acceleration of* Actual Record $cm/sec^2$ | *Max. Acceleration Used* in Analysis $cm/sec^2$ |
|---|---|---|---|
| EL CENTRO | NS | 341.7 | 196.4 |
| | EW | 210.1 | 120.7 |

Study Cases For examination of the connecting types the models shown in table 4 are studied. The Model-2 has no connection. The Models-3 to 6 differ in number of the horizontal braces. The Model-7 is the same as Model-1 without the connectiong beams at the floors. Model-8 differs from Model-1 in having weight unbalance between the two towers. The weight of one tower is different by 8 to 10 % from the other.

Table 4 Description of the Models

| Floor | Model-1 | Model-2 | Model-3 | Model-4 | Model-5 | Model-6 | Model-7 | Model-8 |
|---|---|---|---|---|---|---|---|---|
| R | | | | | | | | |
| 20 | ⊠ | ] [ | ⊠ | ⊠ | ⊠ | ⊓ | ⊠ | ⊠ |
| 19 | ⊓ | ] [ | ⊠ | ⊓ | ⊓ | ⊓ | ] [ | ⊓ |
| 18 | ⊓ | ] [ | ⊠ | ⊓ | ⊓ | ⊓ | ] [ | ⊓ |
| 17 | ⊠ | ] [ | ⊠ | ⊓ | ⊓ | ⊓ | ⊠ | ⊠ |
| 16 | ⊓ | ] [ | ⊠ | ⊓ | ⊓ | ⊓ | ] [ | ⊓ |
| 15 | ⊓ | ] [ | ⊠ | ⊓ | ⊓ | ⊓ | ] [ | ⊓ |
| 14 | ⊠ | ] [ | ⊠ | ⊠ | ⊓ | ⊓ | ⊠ | ⊠ |
| 13 | ⊓ | ] [ | ⊠ | ⊓ | ⊓ | ⊓ | ] [ | ⊓ |
| 12 | ⊓ | ] [ | ⊠ | ⊓ | ⊓ | ⊓ | ] [ | ⊓ |
| 11 | ⊠ | ] [ | ⊠ | ⊓ | ⊓ | ⊓ | ⊠ | ⊠ |
| 10 | ⊓ | ] [ | ⊠ | ⊓ | ⊓ | ⊓ | ] [ | ⊓ |
| 9 | ⊓ | ] [ | ⊠ | ⊓ | ⊓ | ⊓ | ] [ | ⊓ |
| 8 | ⊠ | ] [ | ⊠ | ⊠ | ⊓ | ⊓ | ⊠ | ⊠ |
| 7 | ⊓ | ] [ | ⊠ | ⊓ | ⊓ | ⊓ | ] [ | ⊓ |
| 6 | ⊓ | ] [ | ⊠ | ⊓ | ⊓ | ⊓ | ] [ | ⊓ |
| 5 | ⊠ | ] [ | ⊠ | ⊓ | ⊓ | ⊓ | ⊠ | ⊠ |
| 4 | ⊓ | ] [ | ⊠ | ⊓ | ⊓ | ⊓ | ] [ | ⊓ |
| 3 | ⊓ | ] [ | ⊠ | ⊓ | ⊓ | ⊓ | ] [ | ⊓ |
| 2 | ⊓ | ] [ | ⊠ | ⊓ | ⊓ | ⊓ | ] [ | ⊓ |

[notes] Model-8 is the same in connection as Model-1 and considers weight unbalance.
⊠ : beams and horizontal braces, ⊓ : beams, ] [ : no connection

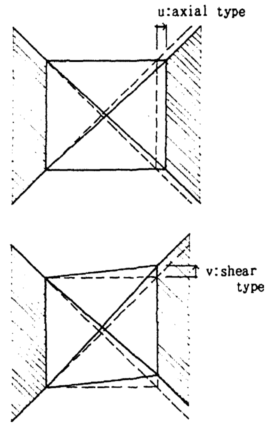



Fig.6 Two Components of Displacement at the Connection

Result Tables 5(a) and (b) show the maximum response displacement-u,-v at the connection parts of Model-1 and 2, respectively, and show the difference caused by the incident time lag and the incident direction. Disp.-u and Disp.-v are the axial components of the relative displacement between the two towers at the connection and the shear component of that, respectively, as shown in Fig.6.

As for Model-1, the maximum Disp.-u and Disp.-v with incident time lag are about 4 times and 20 times of that without it, respectively.

The Max. Disp.-u and Disp.-v with no connection(Model-2) are 31.91cm and 5.02cm, respectively, and those with the proper connections(Model-1) are 0.038cm and 0.512cm.

Fig.7 shows the movement of the 20th floor of Model-1 and 2 at the same period, where is possible to see that the Model-2 with no connection is suffering large torsion while Model-1 is suffering a slight torsional movement.

Maximum response shear forces and torsional moments are shown in Fig.8.

Table 5 Diplacement at connection (Model-1,2)

(a) Axial Component (u) (Unit:cm)

| Floor | Model-1 | | | | | | Model-2 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.0sec | 0.08sec. Time Lag | | | | | 0.08sec. Time Lag | | | | |
| | Max. | Direction | | | | Max. | Direction | | | | Max. |
| | | 0.0° | 90.0° | 68.4° | 158.4° | | 0.0° | 90.0° | 68.4° | 158.4° | |
| 20 | 0.011 | 0.035 | 0.020 | 0.019 | 0.038 | 0.038 | 18.91 | 31.91 | 28.50 | 23.53 | 31.91 |
| 19 | 0.008 | 0.040 | 0.025 | 0.019 | 0.045 | 0.045 | 18.42 | 30.57 | 27.74 | 23.05 | 30.57 |
| 18 | 0.009 | 0.038 | 0.025 | 0.020 | 0.043 | 0.043 | 17.80 | 29.60 | 26.77 | 22.36 | 29.60 |
| 17 | 0.006 | 0.018 | 0.012 | 0.009 | 0.020 | 0.020 | 17.11 | 28.36 | 25.60 | 21.53 | 28.36 |
| 16 | 0.007 | 0.039 | 0.024 | 0.018 | 0.042 | 0.042 | 16.28 | 26.98 | 24.36 | 20.63 | 26.98 |
| 15 | 0.008 | 0.039 | 0.024 | 0.019 | 0.044 | 0.044 | 15.39 | 25.46 | 22.91 | 19.53 | 25.46 |
| 14 | 0.005 | 0.018 | 0.011 | 0.009 | 0.021 | 0.021 | 14.35 | 23.74 | 21.39 | 18.35 | 23.74 |
| 13 | 0.007 | 0.040 | 0.024 | 0.018 | 0.045 | 0.045 | 13.32 | 22.01 | 19.80 | 17.11 | 22.01 |
| 12 | 0.007 | 0.040 | 0.025 | 0.019 | 0.045 | 0.045 | 12.21 | 20.15 | 18.22 | 15.80 | 20.15 |
| 11 | 0.005 | 0.019 | 0.012 | 0.010 | 0.022 | 0.022 | 11.11 | 18.28 | 16.66 | 14.90 | 18.28 |
| 10 | 0.006 | 0.039 | 0.026 | 0.018 | 0.045 | 0.045 | 10.07 | 16.42 | 15.11 | 12.90 | 16.42 |
| 9 | 0.008 | 0.042 | 0.025 | 0.026 | 0.047 | 0.047 | 8.90 | 14.56 | 13.45 | 11.66 | 14.56 |
| 8 | 0.004 | 0.018 | 0.018 | 0.016 | 0.020 | 0.020 | 7.80 | 12.70 | 11.80 | 9.87 | 12.70 |
| 7 | 0.004 | 0.040 | 0.027 | 0.020 | 0.045 | 0.045 | 6.62 | 10.83 | 10.07 | 8.42 | 10.83 |
| 6 | 0.005 | 0.042 | 0.026 | 0.019 | 0.046 | 0.046 | 5.52 | 8.97 | 8.35 | 6.97 | 8.97 |
| 5 | 0.003 | 0.022 | 0.011 | 0.010 | 0.024 | 0.024 | 4.35 | 7.18 | 6.62 | 5.45 | 7.18 |
| 4 | 0.004 | 0.041 | 0.027 | 0.022 | 0.048 | 0.048 | 3.24 | 5.38 | 4.97 | 4.07 | 5.38 |
| 3 | 0.010 | 0.044 | 0.033 | 0.026 | 0.053 | 0.053 | 2.07 | 3.52 | 3.17 | 2.62 | 3.52 |
| 2 | 0.043 | 0.053 | 0.037 | 0.047 | 0.055 | 0.055 | 1.03 | 1.72 | 1.72 | 1.24 | 1.72 |

(b) Shear Component (v) (Unit:cm)

| Floor | Model-1 | | | | | | Model-2 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.0sec | 0.08sec. Time Lag | | | | | 0.08sec. Time Lag | | | | |
| | Max. | Direction | | | | Max. | Direction | | | | Max. |
| | | 0.0° | 90.0° | 68.4° | 158.4° | | 0.0° | 90.0° | 68.4° | 158.4° | |
| 20 | 0.002 | 0.058 | 0.091 | 0.102 | 0.046 | 0.102 | 3.08 | 5.02 | 4.45 | 3.68 | 5.02 |
| 19 | 0.025 | 0.324 | 0.391 | 0.463 | 0.282 | 0.463 | 2.94 | 4.90 | 4.34 | 3.58 | 4.90 |
| 18 | 0.008 | 0.290 | 0.373 | 0.438 | 0.262 | 0.438 | 2.86 | 4.75 | 4.20 | 3.48 | 4.75 |
| 17 | 0.001 | 0.064 | 0.087 | 0.101 | 0.060 | 0.101 | 2.78 | 4.57 | 4.02 | 3.34 | 4.57 |
| 16 | 0.014 | 0.269 | 0.333 | 0.388 | 0.231 | 0.388 | 2.67 | 4.37 | 3.84 | 3.18 | 4.37 |
| 15 | 0.004 | 0.248 | 0.317 | 0.369 | 0.229 | 0.369 | 2.55 | 4.17 | 3.66 | 3.03 | 4.17 |
| 14 | 0.001 | 0.064 | 0.085 | 0.100 | 0.061 | 0.100 | 2.43 | 3.90 | 3.42 | 2.83 | 3.90 |
| 13 | 0.011 | 0.249 | 0.313 | 0.366 | 0.208 | 0.366 | 2.27 | 3.64 | 3.20 | 2.64 | 3.64 |
| 12 | 0.003 | 0.228 | 0.293 | 0.342 | 0.213 | 0.342 | 1.11 | 3.36 | 2.96 | 2.43 | 3.36 |
| 11 | 0.001 | 0.064 | 0.085 | 0.100 | 0.062 | 0.100 | 1.94 | 3.07 | 2.72 | 2.21 | 3.07 |
| 10 | 0.004 | 0.224 | 0.288 | 0.336 | 0.191 | 0.336 | 1.76 | 2.79 | 2.48 | 1.99 | 2.79 |
| 9 | 0.009 | 0.198 | 0.266 | 0.307 | 0.204 | 0.307 | 1.58 | 2.50 | 2.21 | 1.77 | 2.50 |
| 8 | 0.001 | 0.066 | 0.089 | 0.100 | 0.058 | 0.100 | 1.41 | 2.18 | 1.94 | 1.53 | 2.18 |
| 7 | 0.006 | 0.212 | 0.283 | 0.332 | 0.180 | 0.332 | 1.22 | 1.87 | 1.66 | 1.30 | 1.87 |
| 6 | 0.001 | 0.199 | 0.277 | 0.322 | 0.183 | 0.322 | 1.04 | 1.56 | 1.38 | 1.08 | 1.56 |
| 5 | 0.001 | 0.078 | 0.107 | 0.124 | 0.073 | 0.124 | 0.87 | 1.24 | 1.09 | 0.86 | 1.24 |
| 4 | 0.007 | 0.272 | 0.360 | 0.420 | 0.253 | 0.420 | 0.52 | 0.95 | 0.84 | 0.65 | 0.95 |
| 3 | 0.014 | 0.334 | 0.441 | 0.512 | 0.313 | 0.512 | 0.33 | 0.60 | 0.53 | 0.42 | 0.60 |
| 2 | 0.027 | 0.230 | 0.308 | 0.359 | 0.221 | 0.359 | 0.16 | 0.28 | 0.24 | 0.20 | 0.28 |

Fig.7 Trace of the Horizontal Movement (20 FL)

Direction:158.4°
Time lag :0.08sec

(a) T=11.3～12.3sec

(b) 12.3～13.3sec

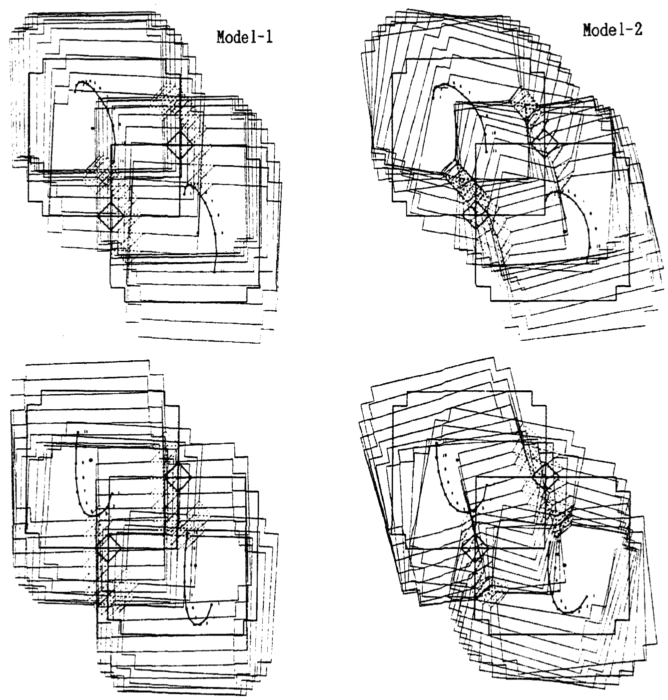
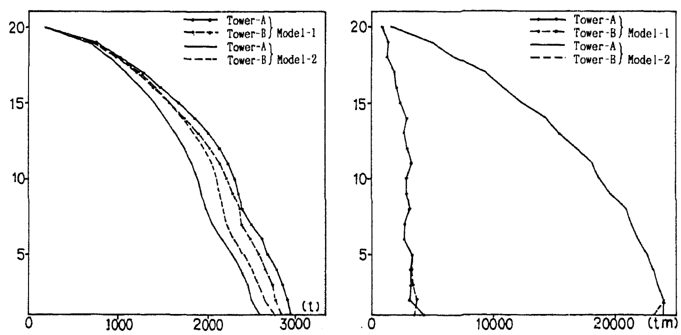
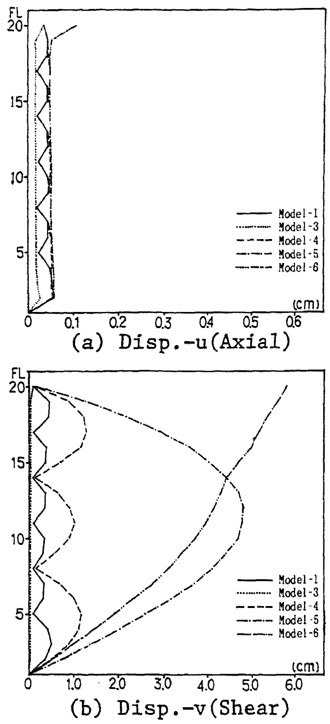



Fig.8 Maximum Response Shear Force and Torsional Moment



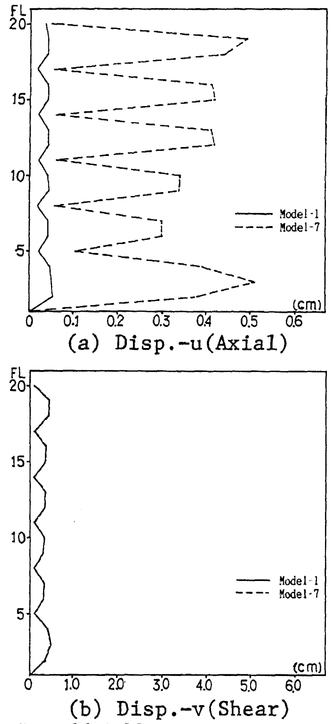

(a) Shear Force (b)Torsional Moment




(a) Disp.-u(Axial)

(b) Disp.-v(Shear)

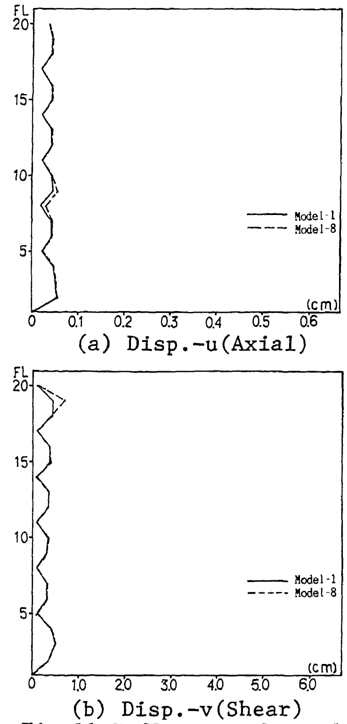
Fig.9 Comparison by Number of Braces




(a) Disp.-u(Axial)

(b) Disp.-v(Shear)

Fig.10 Effect of External Beams




(a) Disp.-u(Axial)

(b) Disp.-v(Shear)

Fig.11 Influence of Weight Unbalance

The response shear in Model-2 is slightly smaller than in Model-1, but the torsional moment is about 5 to 6 times of that in Model-1. This also shows the large torsional moment when there is no connection.

Fig.9 shows a comparison of the response of the models with different number of connecting braces. Disp.-u are about 0.02cm and 0.05cm at the floors with and without the connecting braces respectively even for different models. Disp.-v are about 0.03 cm for Model-3(horizontal braces attached to all floors), and for Model-4 and 5, they are about 0.1cm at the floor with the braces and about 0.5cm, 1.3cm and 9.8cm, respectively, at the floor without the braces.

Fig.10 shows a comparison of the response of the models with or without the external beams having the same braces. Disp.-u of the model without the beams is about 3 and 10 times that of with the beams at the floors with and without braces respectively. Disp.-v are almost the same in all cases.

Fig.11 shows that the connection deformation due to the weight unbalance is so slight that the responses do not differ from each other.

## CONCLUSION

1. By connecting two towers which have individually torsional inclinations, the torsional movement was reduced, the relative displacement was minimized and seismic stability was increased.
2. Incident time lag affects the torsional vibration and the relative displacement at the connection.
3. Weight unbalance has influence in the response shear force and torsional moment, but rarely in the relative displacement at the connection.
4. Working stress of the connecting elements in the final design under seismic loading is less than 0.28 $t/cm^2$ which is about 8% of the yield stress, and it means that the final design is safe enough.