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BASE ISOLATION RETROFIT WORK THAT CAN BE DONE "WHILE A BUILDING IS BEING OCCUPIED" AND SUBSEQUENT LARGE-SCALE ADDITIONS CONSTRUCTED INSIDE THE BUILDING

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SUMMARY

With the end of the period of high economic growth, it is predicted that construction investment will shift away from new projects towards stock maintenance. At the same time, the transition of the economy from one based on production of material goods to one based on information is increasing the importance of "smart buildings." Buildings that contain sophisticated information equipment require a very high degree of seismic resistance; thus, demand is increasing every year for improving methods and technologies for reinforcing the earthquake resistance of existing buildings by base isolation.

In this condition the work of Phase I was done. This was base isolation retrofit work. And the total aria was 682178.7m2. The base isolated structure is connected structure by the four buildings. Each building was constructed from 1973 to 1985. And every building is SRC structure. When we made this base isolated structure we use 264 numbers of natural rubber bearings and 28 wall-type viscous dampers.

After that, work started on Phase II. This involved the construction of a 4725.7m^2 addition of steel structure, bringing the total area of base isolated buildings to 72,472.9 m^2. For this purpose, additional 8 rubber bearings and 4 wall-type viscous dampers were installed. Eventually, there were 272 rubber bearings and 32 wall-type viscous dampers. Most of the addition work was finished by the end of 2003. Presently, minor structures are being constructed on the roof. When they are finished, which should be sometime in 2005, the project will be completed.

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The present addition work was an unusual example of additions made to a structure that was considered substandard under the present Building Standard Law. However, an exception was made in this case because the addition work was done to the base isolated buildings. The present paper reports on various aspects of the project, including the applied technology that was used to undertake the construction plan, and confirmation of the base isolation effect based on subsequent seismic measurements.

INTRODUCTION

The present paper reports on the design and construction of base isolation retrofits and subsequent earthquake observations, as part of an effort to improve the earthquake resistance of existing buildings. The following is a report on four types of technologies/techniques that were developed in the present study:

1) Reinforcement of contiguous buildings by base isolation
2) Base isolation system using wall-type viscous dampers
3) Technology to temporarily and safely accommodate high axial strength of piles
4) Technology for installing base isolation devices while a building is being occupied

1. View of the Project

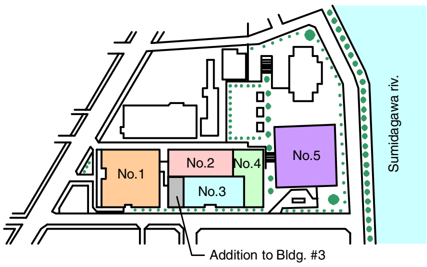
Project name:	Tokyo DIA Building 1-4 Improvement Work Retrofit work and an addition made to Bldg. #3
Location:	1-28-38 Shinkawa, Chuo-ku, Tokyo Mitsubishi Logistics Corporation
Design / Construction / Supervision:	Takenaka Corporation
Use:	Office / computer room
Building area:	Total for Bldgs. 1-4 6,414.5m^2 (including 456.0 m^2 addition in Phase II)
Total floor space:	Total for Bldgs. 1-4 72,472.9m^2 (including 4725.7 m^2 addition in Phase II)
Number of floors / Structure of existing (addition) building:	Phase I SRC, 11 fl. (partly 12 fl.) above and 1 fl. below ground Phase II (addition) S, 12 fl. above and 1 fl. below ground
Weight of existing building:	Base isolation area 1,041,300 kNt (including 41,700 kNt addition)
Work period:	Phase I 1 Dec. 1999 to 30 Nov. 2001 Phase II (addition) 1 Dec. 2002 to 12 Dec. 2003

Figure1-1 Completion of Phase I and Beginning of Phase II (addition)

2. Overview of the plan

Figure 2-1 shows the buildings reinforced in the present study-- the Tokyo DIA Buildings 1-4, which were built from 1973-1985 and are used as computer server buildings. All four buildings have an SRC structure and are of the same height. The owners of the buildings wanted them to be given highly functional base isolation improvements (response acceleration of 200gal or less on each floor) so that not only would the safety of the buildings and their occupants be enhanced during a major earthquake, but computer functions and equipment would also be

protected. To meet these requests the four buildings were considered as one. A proposal was made to cut off parts of the existing cast-in-place concrete piles, install base isolation devices, and give the buildings a foundation base isolation structure.
To meet this demand, it was proposed that during Phase I, the foundations of the four buildings would be integrated as one building, part of the existing cast-in-place concrete piles would be cut out and base isolation devices installed there, and the building would be retrofitted into the foundation base isolation structure.



Building name		Building 1	Building 2	Building 3	Building 4	Addition to Bldg. #3
Number of floors		B1,F11,P3	B1,F11,P3	B1,F11,P3	F12,P2	B1,F12,P2
Total floor space		27,919 m^2	13,766 m^2	16,275 m^2	10,257 m^2	4,726 m^2
Structure	Super structure	Steel-framed reinforced concrete				steel structure
	Foundation	Cast-in-place pile ϕ 1100～1800				Cast-in-place pile ϕ 1100-1500

Figure 2-1 Overview of building

The earthquake resistance apparatus consisted of 264 natural rubber bearings and 28 wall-type viscous dampers. The buildings are occupied on a 24-hour basis and house over 3000 workers, but all construction work, including the cutting, could be completed with minimal noise and vibration while the buildings were being occupied.
Figure 2-3 shows the standard floor plan, while Figure 2-4 shows the layout of the base isolation devices. A rubber bearing was installed on the upper end of each existing pile. Modified rubber bearings, including 230 rubber bearings of 700 ϕ, and 14, 11, 4, and 5 rubber bearings of 750 ϕ, 800 ϕ, 900 ϕ and 1000 ϕ, respectively, were set up to respond to axial forces. In the interest of providing balance, 14 wall-type viscous dampers were installed on each side. Figure 2-4 is a longitudinal profile after completion of the base isolation work. The total

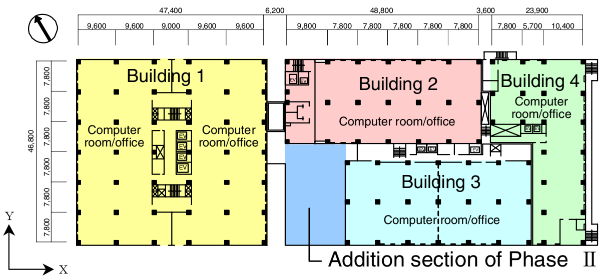


Figure 2-2 Standard floor plan

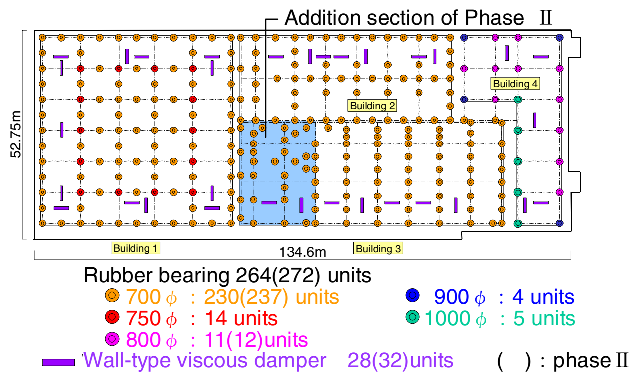


Figure 2-3 Layout of base isolation devices

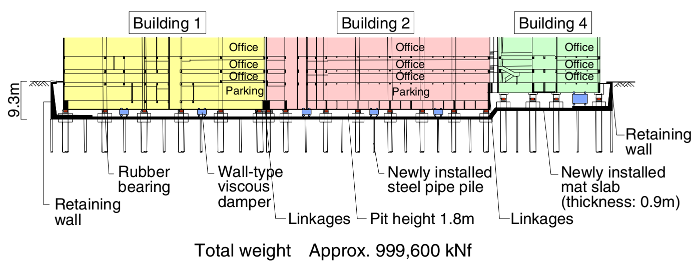


Figure 2-4 Longitudinal profile after completion of the base isolation work

height of the retaining wall of the newly-built base isolation pit is 9.3m, and the legs are 1.0m thick. The outer thickness of the mat slab is 1.0m, and 0.90m in the central area. The weight of the retaining wall is supported by 21 new cast-in-place piles, while the mat slab is supported by 132 steel pipe piles (457.2 ϕ). In the 1.8m space between the old and new mat slabs there is a wall-type viscous damper installed. In addition, as previously reported there is a temporary capital on the head of each pile, and a rubber bearing attached on top of that.

During Phase II, the section shown in Fig. 2-3 was given an addition of a steel structure. In Phase I, this section was a four-story steel structure (including one basement floor) and during Phase II, this four-story steel structure was demolished and a steel structure of 12 floors above and one floor below ground was constructed. For this purpose, some of the mat slabs were removed and seven cast-in-place concrete piles (four 1300 ϕ and three 1500 ϕ) were installed. The weight of the additional structure was supported by these cast-in-place concrete piles used in conjunction with the existing 1000 ϕ piles. Prior to utilizing the existing piles, profiles of existing piles were checked for concrete deterioration, compression strength and defects using integrity tests. As base isolation devices, eight additional rubber bearings, consisting of seven 700 ϕ units and one 800 ϕ unit, and four wall-type viscous dampers, two along the X-axis and two along the Y-axis, were installed in the addition section. These additions resulted in a total of 272 rubber bearings and 32 wall-type viscous dampers.

3. Confirmation of the influence of foundation linkages between buildings

The foundation beam linkage of the buildings is shown in Figure 3-1. As can be seen in the figure, linking the buildings with PC steel bars has made it possible to change the four buildings into one base isolation unit. In addition, the dynamic analysis model in Figure 3-2 examines the effect of Styrofoam on the expansion sections of Buildings 2 and 3. The Styrofoam was modeled as a compression spring in the seismic response analysis. As a result, contact with the expansion area had only a minimal effect on the dynamic state, as can be seen in Figure 3-3. Therefore, it was decided not to improve the expansion joints in the aboveground floors. In addition, the PC steel bars used to connect the foundation beams were also analyzed by spring evaluation. The base isolation foundation of each building moved in roughly the same phase, so no large shear force or tensile force occurred. As a result, the design was considered to be safe.

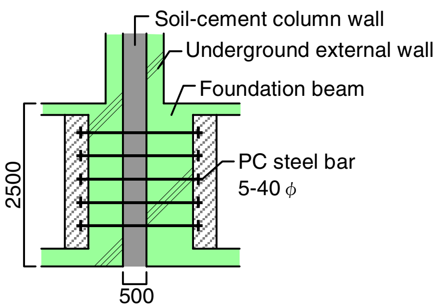


Figure 3-1
Linkage of foundation beams

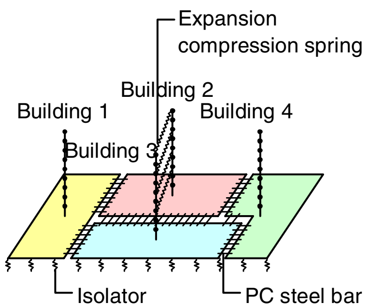


Figure 3-2 Dynamic analysis model for investigating linkage of base isolation

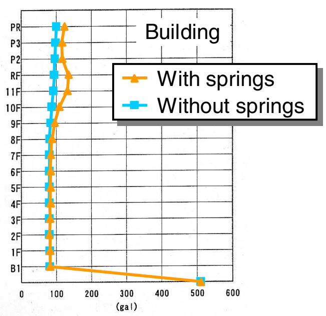


Figure 3-3 Effect of expansion joints on dynamic properties of the buildings

4. Development of base isolation system using the wall-type viscous dampers

4.1 Selection of the rubber bearings

The rubber bearings used in this project had a long-term allowable surface pressure of $\sigma \leqq 15\mathrm{N/mm^2}$ and $G=0.4\mathrm{N/mm^2}$. This made it possible to have a primary natural period of less than four seconds for the base isolation structure.

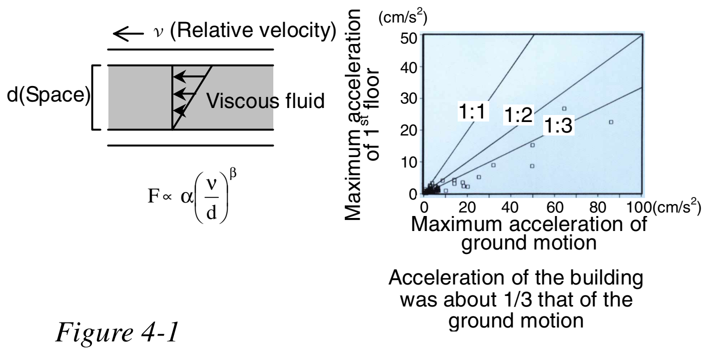


Figure 4-1
Effect of base isolation during minor earthquakes

4.2 Effect of the viscous damper

Originally, this damper was not a wall type but a horizontal one. In 1983, performance tests were commenced to determine the proper applications for the horizontal type (*1). Development continued after that to the point where it was used in an actual building, an employee housing unit of Takenaka Corporation in Funabashi City (Evaluation No. 5). Long-term earthquake observations made at this building have shown the effectiveness of base isolation, especially during minor earthquakes (see Figure 4-1). Unfortunately, giving the horizontal damper high capacity would result in a lot of "dead space" in the floor plans.

4.3 Development of the wall-type viscous damper

If the damper could be put on a wall and still be large enough to resist major shear, the problem with dead space would be solved. Figure 4-2 diagrams such a damper. However, if the damper is a wall type, it is necessary to be able to handle out-of-plane forces and torsion (including the mitigating of construction errors). This required the use of fasteners, whose suitability was confirmed as follows:

1) Verification of an equation to show the shear resistance of the wall-type viscous damper.
2) Confirmation of the ability of the fastener to handle high-velocity, multi-directional deformation.
3) Confirmation of the ability to handle movement in all directions using actual equipment.

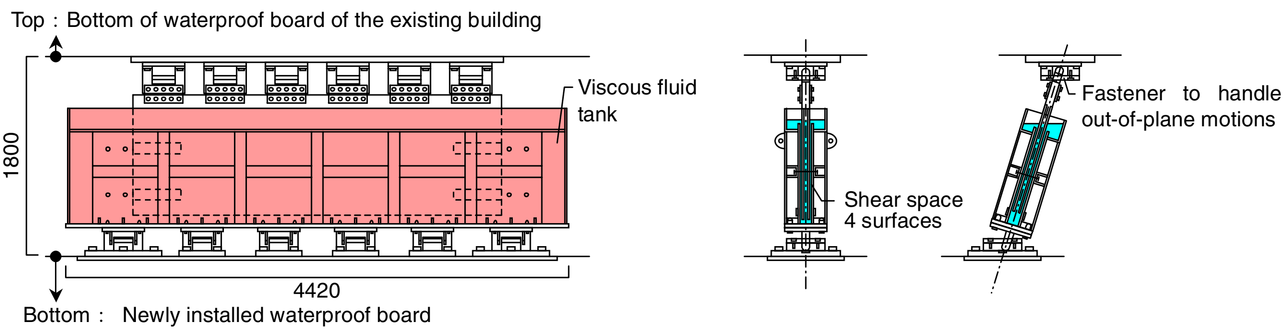


Figure 4-2 Overview of wall-type viscous damper

4.3.1 Verification of an equation to show the shear resistance of the wall-type viscous damper

Using a specimen of 65% actual size (Photo 4-1), oscillation experiments were conducted from 18 Oct. to 2 Nov., 1999 with sine and random (seismic) waves. The results, which are shown in Figure 4-3, were used to formulate an experimental equation. The experiment also confirmed the feasibility of mechanisms for four shear layers using two interior steel sheets (*2).

Photo 4-1 Test specimen (65% actual size)

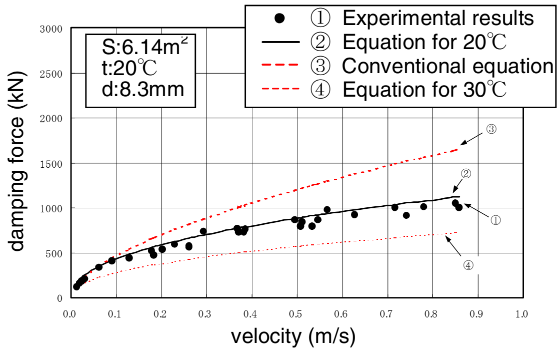


Figure 4-3 Experimental results

4.3.2 Confirmation of the ability of the fastener to handle high-velocity, multi-directional deformation

The test specimen consisted of a mini model (Figure 4-4) having fasteners in two places and a shear resistance area of 2.36m^2. The experiments were conducted from 25 Aug. to 18 Sep., 2000. The basic input force was set so that the velocity oscillation of the building would be 30cm/sec (50 cm/sec in actual size) for the primary natural frequency of this building (3.8 sec, 0.26 Hz). The high-velocity capability of the fastener was confirmed for the input force directions of in-plane, out-of-plane, and 45 degrees. A detailed diagram of the fastener is shown in Figure 4-5. The fastener can simultaneously rotate and slide out of plane.

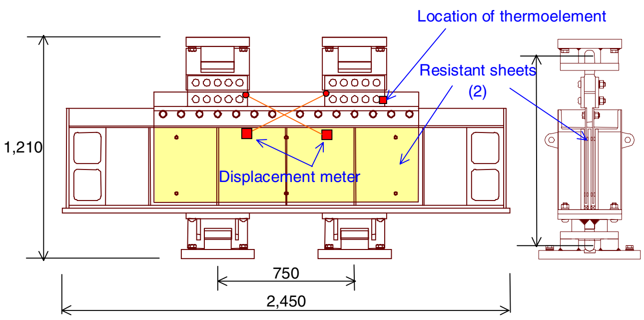


Figure 4-4 Mini model of wall-type viscous damper

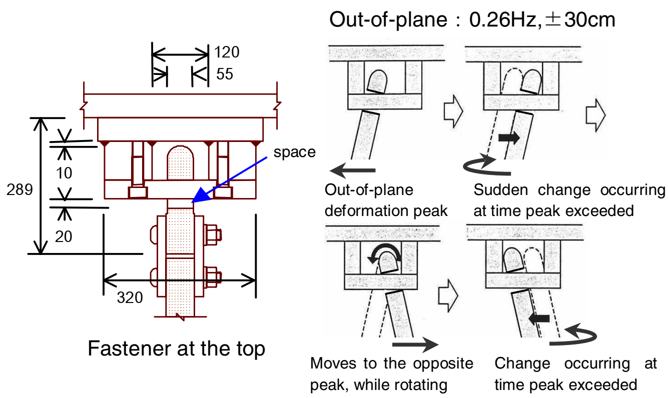


Figure 4-5 Detailed diagram of the fastener

4.3.3 Confirmation of the ability to handle movement in all directions using actual equipment

To confirm the performance of the wall-type viscous damper at the time of completion of the actual equipment, movement was measured using input forces of in-plane, out-of-plane and 45 degrees. Verification of the ability to handle the movement in all directions and simultaneous measurement of damping ability during these experiments confirmed that the desired performance had been achieved (*3).

4.4 Confirmation of the effectiveness of base isolation

The result of analysis shows the end of phase Ⅰ, but the result of phase Ⅱ is nearly equal to phase Ⅰ.

4.4.1 Target performance

As can be seen in Table 1, target performance was set for two levels: 25 and 50 Kine.

Table 4-1 Target values for seismic response

Measuring point	Item	25 Kine	50 Kine
Superstructure	Relative story drift angle	1/2000 or less	1/1000 or less
	Response acceleration	200 gal or less	200 gal or less
	Allowable unit stress of materials	Short-term allowance	Short-term allowance
Base isolation layer	Allowable horizontal deformation	28 cm	42 cm
	Allowable shear distortion	Stable deformation 200%	Max. deformation at which performance maintained 300%
	Tensile stress	Does not induce tensile stress	Does not induce tensile stress
Foundation	--	Does not exceed allowable unit stress	Does not exceed elastic limit strength

4.4.2 Input seismic motion

Input seismic motions included three standard recorded motions (EL1940NS, TA1952EW, HA1968NS) and two typical model motions that considered local characteristics. The two model motions were based on the Great Kanto Earthquake of 1923, the most destructive seismic event in modern Japanese history. These two model motions are referred to as Kanto-Shinkawa A and Kanto-Shinkawa B, respectively.

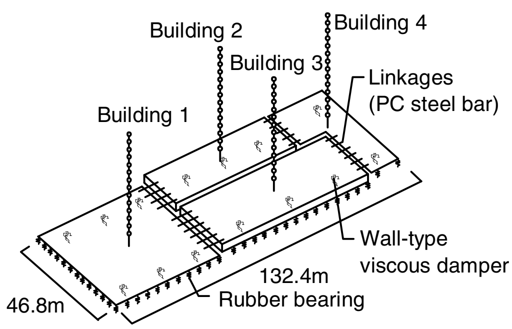


Figure 4-6 Analytical model

4.4.3 Analytical model of seismic response

1) Superstructure

Figure 4.6 shows the three-dimensional analytical model. Its superstructure is modeled as a mass point and its foundation as a frame. The restoring force characteristics of the superstructure were set in the origin-orientation tri-linear model. Attenuation was set as 3% for the motion of the primary natural frequency. In addition, the 40 ϕ PC steel bars of the linkage sections of the buildings were evaluated as spring elements that connect foundation sections.

2) Base isolation layer

The 264 rubber were modeled as horizontal elastic springs. 28 wall-type viscous dampers were evaluated using the Equation (4-1) which was obtained in preliminary experiments (*4).

4.4.4 Results of the analysis

1) Natural period

As the results of the characteristic value analysis, the primary natural period of the entire system was calculated as approximately 3.8 seconds, with fluctuation resulting from the velocity dependence of the damping coefficient.

2) Response acceleration, displacement.

The analysis at the 50kine level using the three standard recorded seismic motions suggested that the superstructures of all four buildings behaved as a single mass, and in the residential floors (11th floor and below) acceleration was not more than 100gal, and deformation did not exceed 25cm.

Table 4-2 Results of model wave response analysis of the y-axis

	Input seismic motion		Response acceleration (Building' center of gravity)			
	Name	Maximum acceleration (Maximum velocity)	Building 1	Building 2	Building 3	Building 4
Acceleration	Kanto-Shinkawa A	277.8(58)	94.1	92.1	91.4	92.3
	Kanto-Shinkawa B	347.0(42)	80.3	82.2	80.0	78.9
Displacement	Kanto-Shinkawa A	—	24.3	24.3	24.3	24.3
	Kanto-Shinkawa B	—	20.0	20.0	20.0	20.0

＊The response acceleration (cm/s^2) is the value for the 11th residential floor. Displacement (cm) is shown as the value for the base isolation layer.

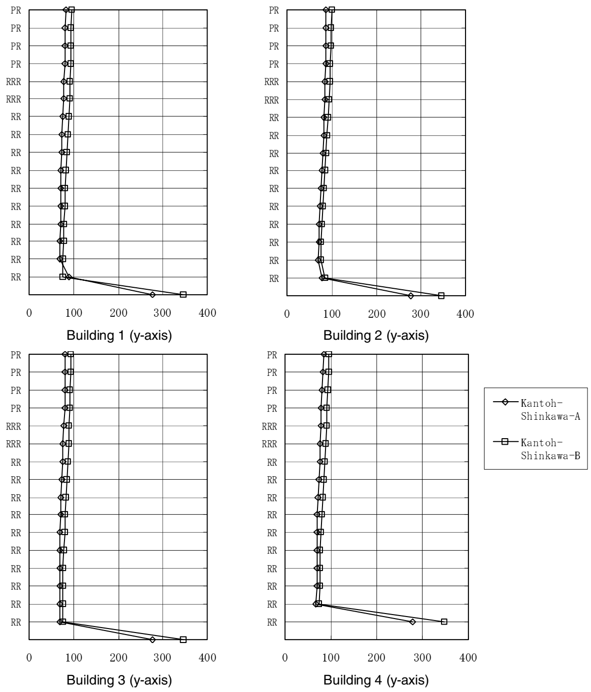


Figure 4-7 Acceleration

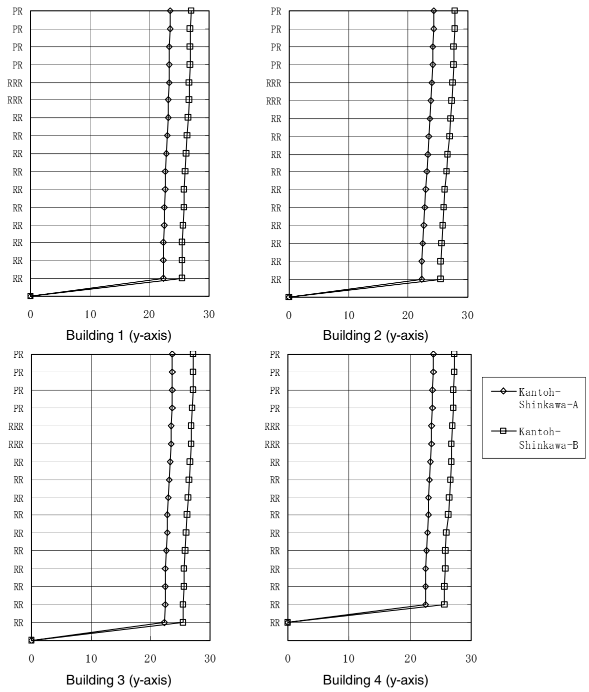


Figure 4-7 Displacement

4.4.5 Torsion

In all analyses (including levels and discrepancies in apparatus), there was a maximum of 2cm torsion in the y-direction in the corners of the buildings, but it was determined that this had no adverse effect.

4.4.6 Wind-induced load

Considering the roughness, gust coefficient, etc., we estimated the lengthwise deformation, and arrived at values of 3cm for 50 years, and 7cm for 500 years. These values were determined not to pose a problem.

*1 Proceedings from the 1983 Conference of the Architectural Institute of Japan: An investigation of base isolation support equipment that uses rubber bearings (Part I), Investigation of energy absorbing equipment.
*2 Proceedings from the 2002 Conference of the Architectural Institute of Japan: Application of wall-type viscous dampers to base isolation structures, (Part I) Verification tests of damping properties.
*3 Proceedings from the 2002 Conference of the Architectural Institute of Japan: Application of wall-type viscous dampers to base isolation structures, (Part 2) Verification tests of abilities of wall-type viscous dampers to handle out-of-plane deformation.
*4 Report on the evaluation of base isolation construction: The Tokyo DIA Buildings 1-4.

5. Development of a method for constructing temporary high axial-force support piles using PS fasteners

We developed a technique wherein a maximum 12749kN of axial force of piles would be accommodated by temporary members installed for that purpose during the cutting of the piles. The axial force during this time includes:

1) adhesive strength between the mat slab for the permanent structure and the existing piles,
2) shear strength of anchor bars,
3) pressure generated between cast-in-place concrete strengthening on the mat slab and existing piles to which the concrete strengthening is fastened with PC steel bars.

Figure 5-3 shows the design equation. As was shown in Figure 5-1, the axial force from the upper foundation beams was transmitted through the four temporary strengthening steels and hydraulic jacks to the bottom of the piles.
After an experiment using a 1/6-scale model to verify the basic conditions, a 1/2-scale model was used to verify the performance. During this experiment, a degree of safety above the design level was maintained. As a result, no excessive deformation was seen during the installation of the 264 base isolation devices.

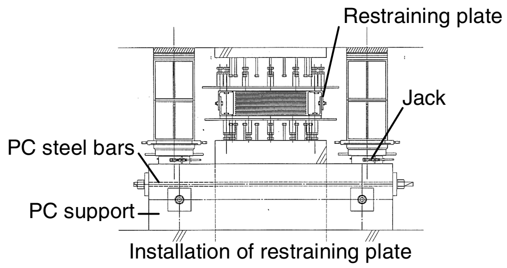


Figure 5-1 Temporary support

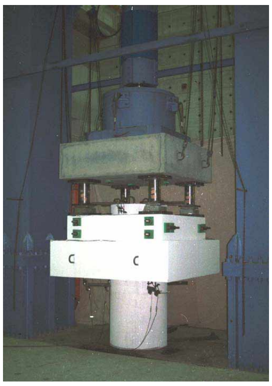


Photo 5-1
Test for temporary support

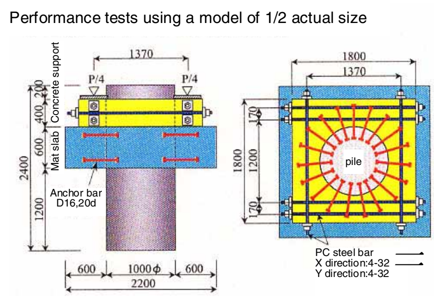


Figure 5-2
Test specimen for temporary support

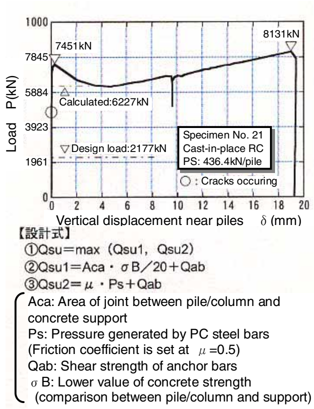


Figure 5-3
Results of experiments

6. Base isolation work that can be done while a building is occupied

6.1 Overview of the new technology

Table 6-1 gives an overview of the new methods that allow foundation base isolation work to be constructed while a building is being occupied.
We will present these developed technologies at the another chance, because of the less manuscripts space.

Table 6-1
Methods developed for Base isolation work that can be done while a building is being occupied

①	Steel pipe pile pressure installation
②	Base isolation device installation
③	Steel stud installation
④	Pressure injection of highly fluid, expansive quick-drying mortar
⑤	Joining buildings using PC steel bars
⑥	Techniques for enhancing safety during earthquakes

7. Earthquake observation records

Earthquake observations have been carried out at the Tokyo Dia Buildings since the base isolation work was completed. Two of the recorded earthquakes which occurred in the Tokyo area in May 2003 had a Japanese seismic intensity of 3. The following record is the acceleration history curves registered ① below the base isolation layer of Building #3, ② at the floor of the first story of Building #1, and ③ at the floor of the eleventh story of Building #1, and ⑥ at the 15th story of the adjacent steel office building.

The following earthquakes were recorded:
(1) 12 May 2003, 00:57; epicenter, southern Ibaraki Prefecture, 35.8N 140.01E 60Km M5.1
(2) 26 May 2003, 18:25; epicenter, northern Miyagi Prefecture, 38.8N 141.80E 60Km M7.0

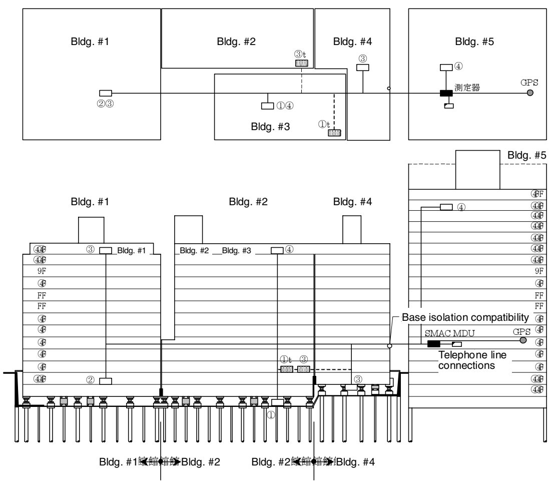


Figure 7-1 Location of seismographs

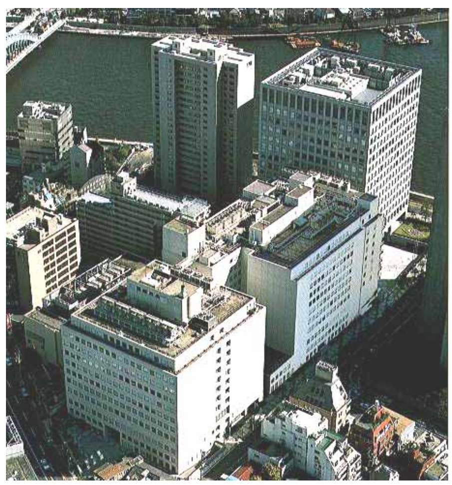


Photo 7-1 Positional relationship with adjacent

Figure 7-1 shows the locations of the seismographs while Photo 7-1 shows the relation between the buildings of this study and adjacent buildings. Tables 7-1 and 7-2 show the maximum accelerations in the X and Y directions for each location.

Table 7-1 Maximum acceleration for 12 May 2003 earthquake 00:57 (Unit : gal)

Position of seismograph		X	Y
⑥	15F, Adjacent steel structure (not base isolated)	29.2	31.8
③	11F, Bldg. #1 (base isolated)	8.4	11.8
②	B1F, Bldg. #1 (base isolated)	8.2	5.1
①	Bldg. #3 input	7.5	8.8

Table 7-2 Maximum acceleration for 26 May 2003 earthquake 18:25 (Unit : gal)

Position of seismograph		X	Y
⑥	15F, Adjacent steel structure (not base isolated)	50.6	19.7
③	11F, Bldg. #1 (base isolated)	17.7	6.9
②	B1F, Bldg. #1 (base isolated)	9.4	4.0
①	Bldg. #3 input	17.3	8.0

sign ○ shows the next record point.

Seismograph installation plan 6 of 3-channel sensors installed

1) On mat slab of lower portion of Bldg. #3
2) On floor of pump room, B1F, Bldg. #1
3) In cable shaft→B shaft, 11F, Bldg. #1
4) F shaft, 11F, Bldg. #3
5) In foundation beam, 1F, Bldg. #3
6) EPS (K shaft), 15F, Bldg. #5

Measuring devices (SMAC-MDU): Central monitoring room, 3F, Bldg. #5

GPS: window side facing Sumida River, Central monitoring room, 3F, Bldg. #5

Both the graphs and charts confirm the base isolation effect during a minor earthquake. Furthermore, we can see that maximum acceleration on the 15th floor of an adjacent building that was not base isolated was 2-3 times greater than that of input waves.

Figures 7-2 and 7-3 show, respectively, the record of the deformation orbit of the base isolation layer and the deformation orbit that was obtained from the acceleration analysis. The two figures show a similar trend.

(1) Earthquake of 12 May 2003, 00:57

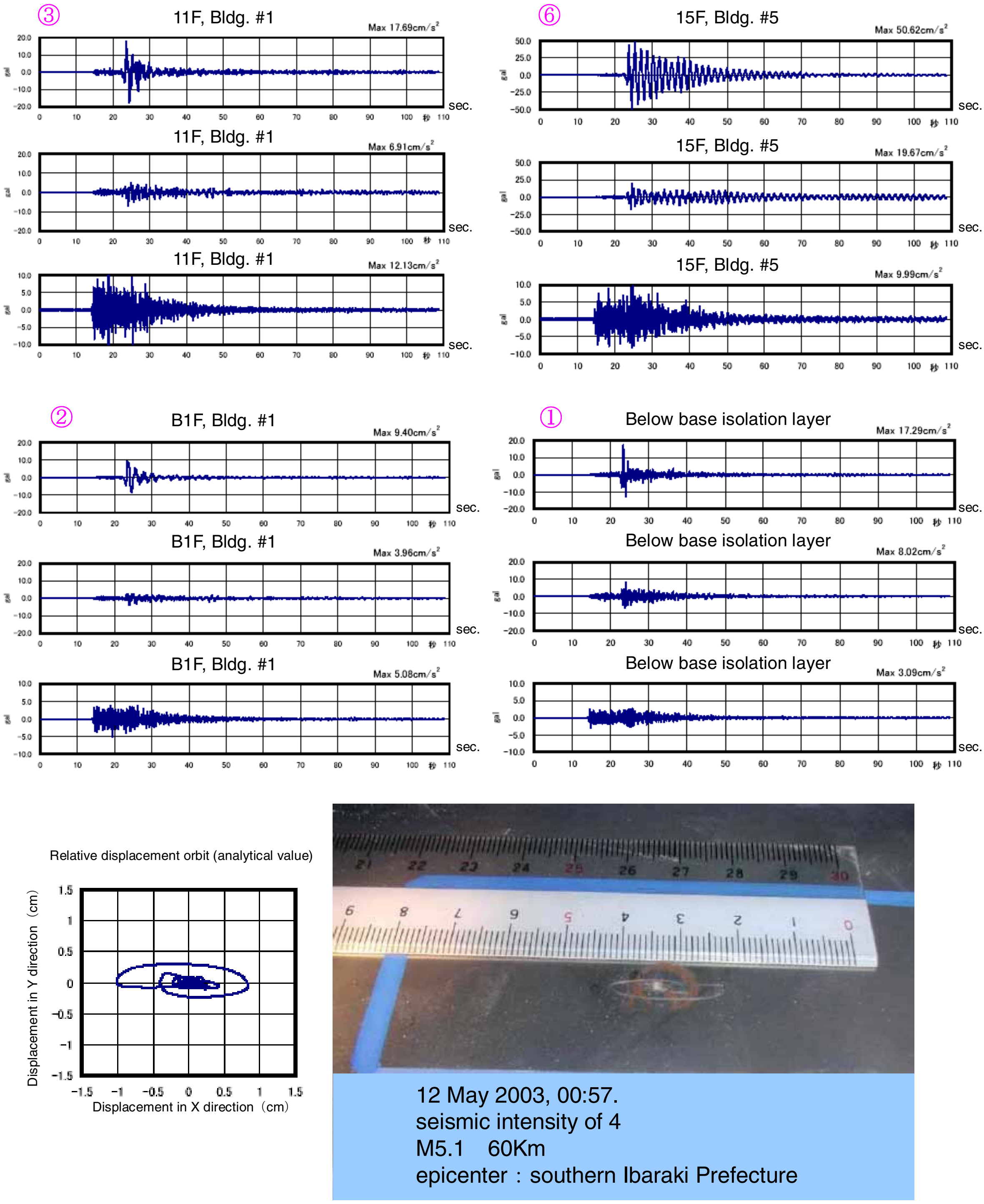


Figure 7-2　Relative displacement orbit of the base isolation layer 1 that occurred during the earthquake of 12 May 2003, 00:57.

(2) Earthquake of 26 May 2003, 18:25

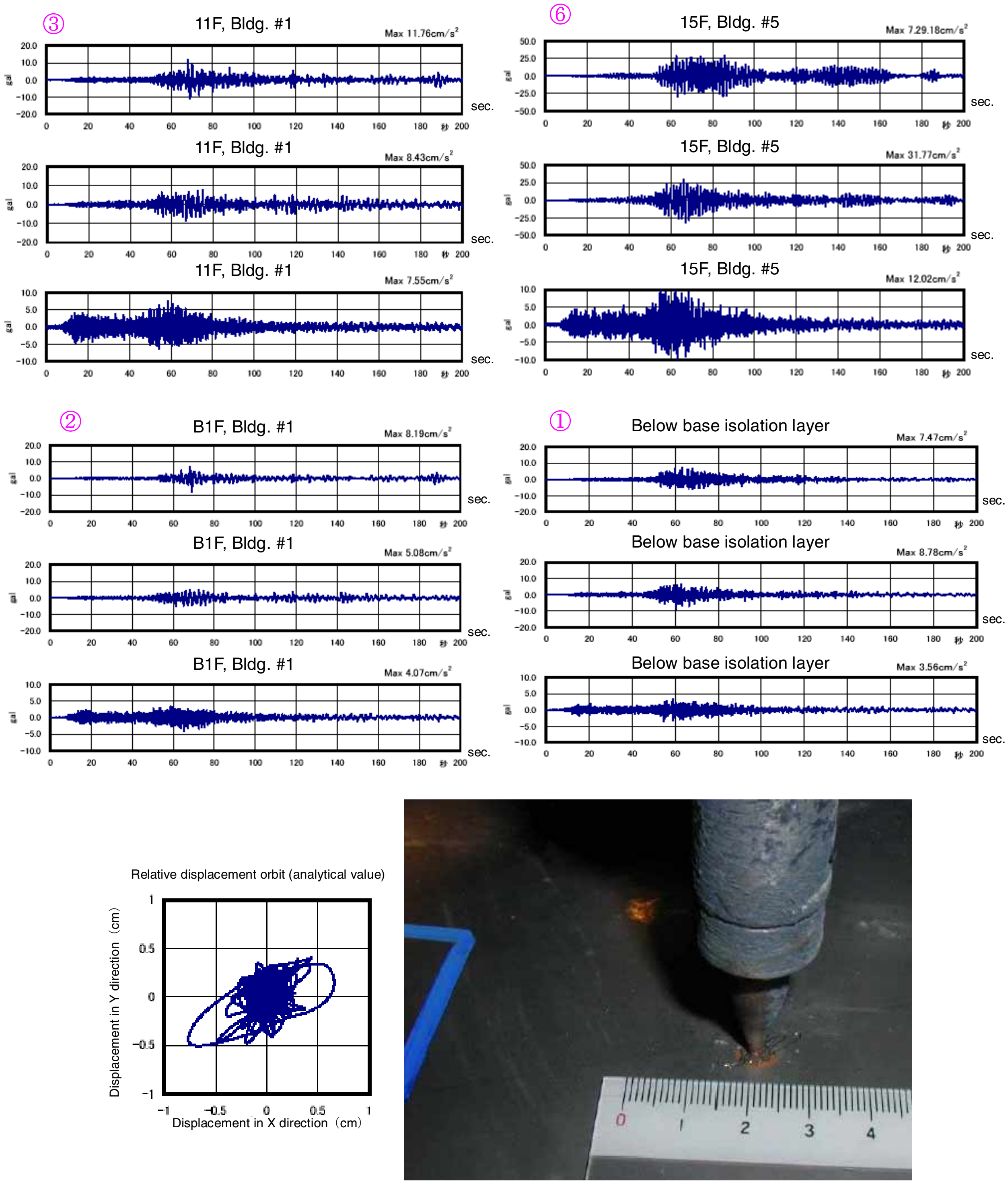


Figure 7-3 Relative displacement orbit 1 of the base isolation layer that occurred during the earthquake of 26 May 2003, 18:25

8. Concluding remarks

The base isolation retrofit work of the Tokyo Dia Buildings #1-4 was divided into two phases: Phase I, which took 27 months and was completed in late November 2001, and Phase II, which took 14 months and was completed in late December 2003. Further construction is expected to be completed in 2005. The main concerns with undertaking the project while the buildings are occupied are 1) maintaining long-term safety during the construction period, and 2) maintaining safety during an earthquake. Therefore, stress analysis and measuring control have been conducted while the work is being done. The results of these activities will be reported at a later date. The important things to note here are that the base isolation retrofit work has been effective and earthquake observations made as part of the project confirmed that it has performed satisfactorily during minor earthquakes.