A CASE OF STRUCTURAL DESIGN IN WHICH VISCOUS DAMPERS ARE USED TO ENHANCE EARTHQUAKE RESISTING PERFORMANCE OF A BUILDING

Yukihiro Tokuda[1] and Kenzo Taga[2]

[1] *Senior Structural Engineer, Structural Engineering Dept. , NIKKEN SEKKEI LTD,Japan*
[2] *Dr.Eng.,Reg.Consulting Engineer,Japan Deputy Principal, Structural Engineering Dept., NIKKEN SEKKEI LTD,Japan*

ABSTRACT :
In recent years, viscous-type, seismic energy absorption type devices have been well developed and have come into wide use in Japan, resulting in increase in use of such devices as oil dampers for high-rise buildings and for seismically isolated buildings. The viscous type devices have been employed by focusing on the fact that viscous type device is superior to hysteresis type device in that viscous type devices display damping effect even under small or medium earthquakes and in that the viscous type devices display stable performance for accumulated deformation. With regards to use of viscous type damper as energy absorption device, this paper will introduce an instance of high-rise building actually designed and constructed. In this high-rise building, the 1st basement was designed as soft first story in which dampers are collectively placed for intensive-type vibration damping. In the soft story, columns are made of 350-mm-diameter thick, high-strength steel pipes (590N/mm^2 class steel) to ensure large elastic limit deformation of main frame, thus enhancing damping performance.

KEYWORDS:
viscous type damper , soft first story, seismic damage control

1. INTRODUCTION

In recent years, viscous type seismic energy absorption devices have been well developed and come into wide use in Japan, resulting in increase in use of such devices as oil dampers for high-rise buildings and seismically isolated buildings. In high-rise buildings, the distributed vibration control structure in which dampers are provided on all floors above the ground is usually adopted. This paper introduces a high-rise office building in which attenuation type viscous dampers are intensively provided on the fist basement designed as the soft first story (intensive vibration control on the first basement).

This structural concept has been known for many years (bibliography items [1] to [4]), but is adopted at this scale introduced here probably for the first time in Japan.

In this building, dampers are provided intensively on the soft story whose elastic deformation during earthquake is made large on purpose so that the attenuation performance is fully exerted, the earthquake resistance near the seismically isolated structure is assured, and the economic efficiency similar to the distributed vibration control is achieved.

2. OUTLINE OF BUILDING

This building is designed as a new clubhouse of the Osaka Bar Association on the site of the joint government building of legal section. The building offers beautiful harmony with the landscape of “Nakanoshima” representing the river city of Osaka, enjoys the landscape, lets in natural light until its every corner, is quiet and comfortable, and expresses throughout the building the philosophy of the Osaka Bar Association, “transparency of activities, openness to citizens, continuity of the organization and environmental consciousness” as the symbol of the Osaka Bar Association.

There are various conference rooms and office rooms on typical floors which are the 5th floor and above. With regard to lower floors, there are entrance open space vaulted from the 1st to 3rd floors, and main conference room available for assemblies of all members on the 2nd floor. There are a counseling room for citizens on the 1st floor, and a restaurant open to citizens on the basement. This building is designed as a "clubhouse open to citizens".

The appearance is simple, and gives the feeling of transparency. The exterior designed as a lattice of extremely slender columns and beams consists of large ceramic plates on beams and columns on high floors, bricks on exterior walls on low floors and glass.

Figure 1: Appearance of building

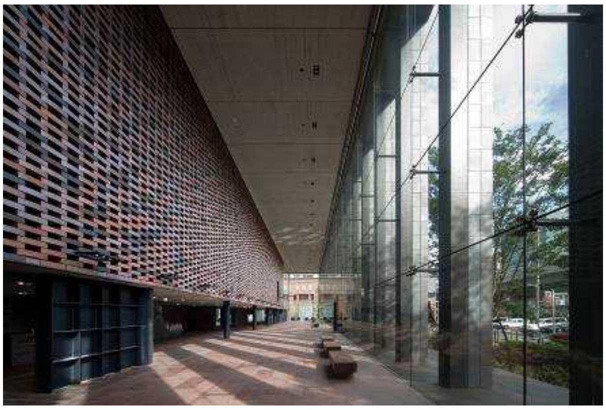

Figure 2: Entrance lobby

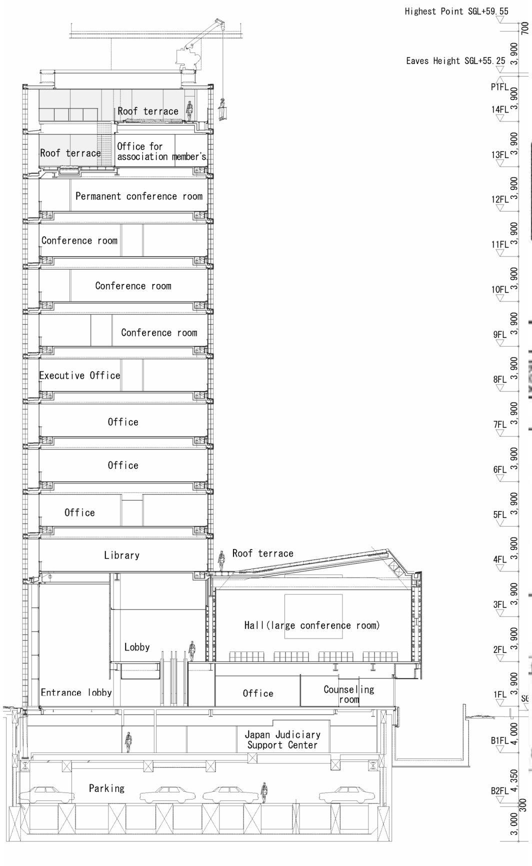

Figure 3: Sectional plan

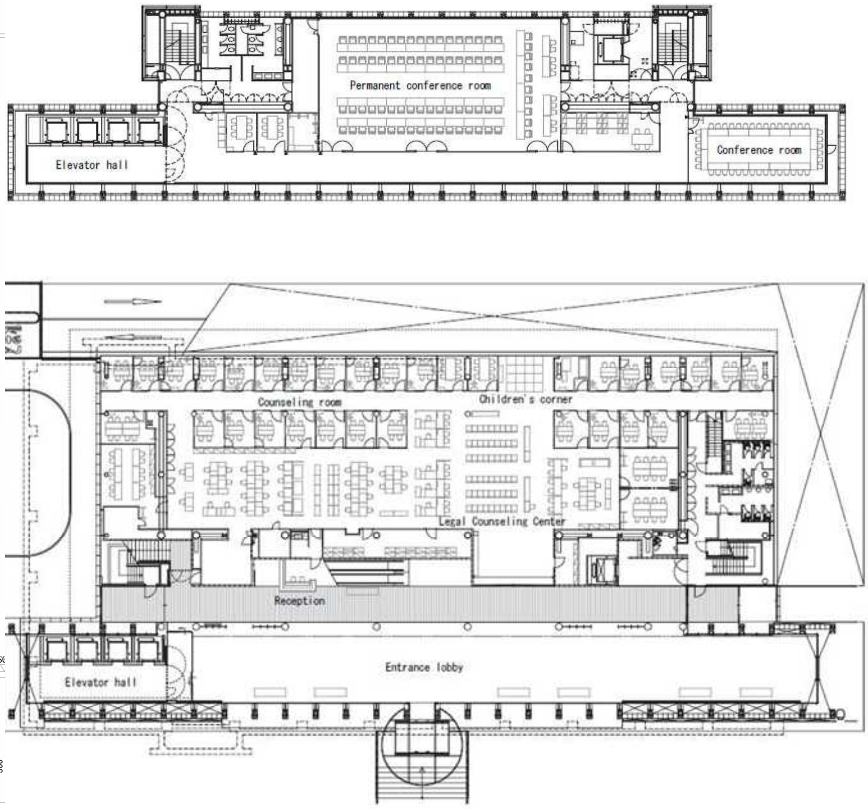

Figure 4: Floor plan of 12th and 1st floors

The characteristic structural frame forming the façade is made by small-diameter columns (centrifugally cast thick steel pipes of 300 mm in diameter) provided at 2,700 mm intervals on the outer circumference.

Building name: Osaka Bar Association Building
Address: 1-1-2 Nishi-temma, Kita-ku, Osaka City, Osaka
Number of floors: 14 floors above the ground, 2 floors below the ground and 1 floor as the pent house
Total floor area: 17037m2 Building height: GL+55.25m Major applications: Offices and motor garage
Design and supervision: NIKKEN SEKKEI LTD. Construction: OBAYASHI Corporation
Structure type: 1st basement and above: Steel structure (CFT in columns partially)
2nd basement: Steel-reinforced concrete structure (reinforced concrete structure partially)
Frame: Above ground: Axial brace and rigid frame with earthquake-resisting walls made of steel plates
1st basement: Rigid frame with vibration control devices
2nd basement: Rigid frame with bearing walls made of reinforced concrete
Major steel type: SN490B, STKN490B, LY225 and Cast steel pipes equivalent to SA440

3. STRUCTURE PLAN

The following two points are important issues in the structure plan.

(1) Achieving the façade consistent with the construction plan and assuring high earthquake resistance

Based on the construction plan policy, the "transparent façade" is made of columns and beams looking as slender as possible in the outer circumference frame, and offices designed as a skeleton glass box having space without columns are formed inside the frame. The delicate façade is required to have an exterior frame type structure and high earthquake resistance.

Figure 5: Façade on south side

Figure 6: Oil dampers intensively provided on vibration control story

(2) Utilizing the existing underground structure

The structure plan is required to permanently use the existing underground structure as a part of the new building in some portions and use temporarily for construction purpose in other portions, mitigate environmental loads by reducing dismantling waste and noise, and give the durability similar to new construction to the existing structure to be used permanently.

The following sections describe how these issues are solved in the design by mainly adopting the "intensive vibration control structure" engineering.

Figure 7: Restaurant on 1st basement

4. ADOPTION OF SOFT FIRST STORY

There is a conventional design concept to make the lowest story (1st basement in this building) soft on purpose and isolate it from ground motions (soft first story). The structure of this concept has become rationally feasible recently by adoption of damping devices and high-strength (highly elastic) steel which are supplied generally.
This building adopts (centrifugally cast) thick circular steel pipes of small diameter equivalent to SA440 for columns on the 1st basement, and uses pins in the column plinth so that the 1st basement is more flexible against horizontal forces than other stories.
As a result, regardless of the fact that the primary characteristic period is usually approximately 1.5 seconds in a building of approximately 55m in height, the primary characteristic period in this building can be set to approximately 2.0 seconds after steel dampers are yielded. By giving proper attenuation, the maximum story drift is reduced to approximately 1/100 in this building during level 2 earthquake motions on the 1st floor and above where dampers are not provided. The story drift is approximately 1/70 (elastic) on the 1st basement where dampers are intensively provided, and the deformation follow-up capability is especially considered for finishing materials on the 1st basement. There is another concept to set the soft story on the 1st floor, but the soft story is set on the basement in this building. Because the design is restricted to assure the deformation follow-up capability of armoring materials, such restriction is avoided on the 1st floor in this building.
Dampers selected at first are attenuation type viscous dampers (oil dampers) which effectively mitigate deformation while holding the equivalent period of the vibration control story for a long time. Combined together are hysteresis type steel dampers which have been used in many buildings and are made of steel LY225 of low yield point to assure high cost performance of the attenuation effect during large earthquake.

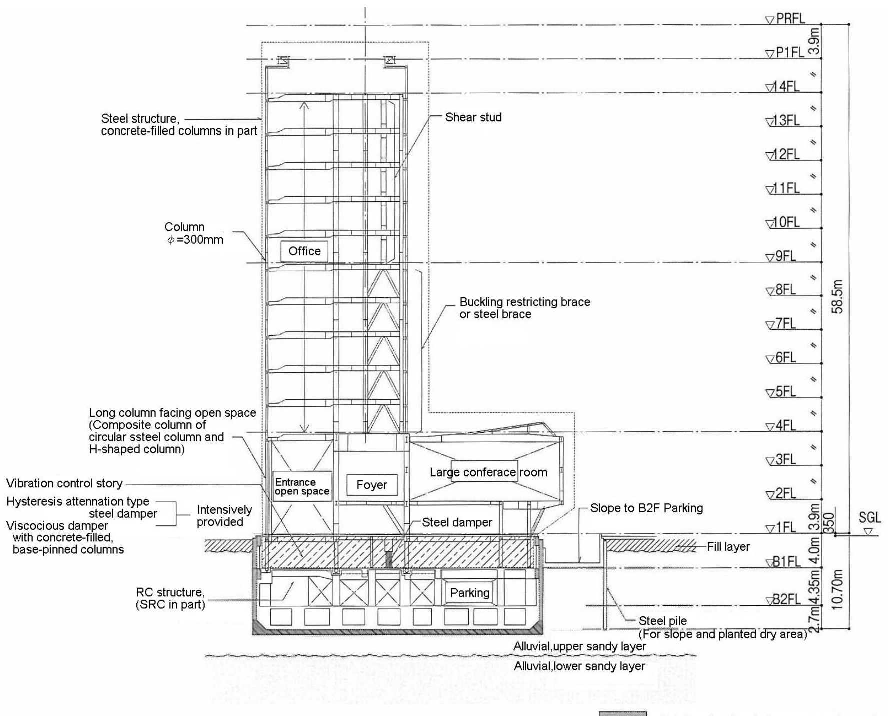

Figure 8: Structural concept drawing

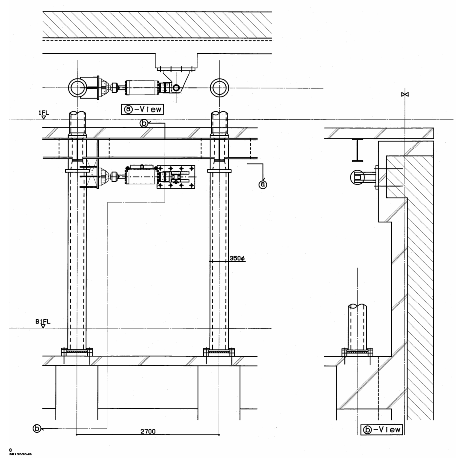

Figure 9: Underground exterior walls and oil dampers

Viscous type attenuation damper: Oil damper Relief load 490 kN type : 8 units
1760 kN type : 10 units
Hysteresis type damper: Stud type shear yielding panel (PL-6 and LY225): 8 units

Table 1: Damper rigidity ratio and bearing force ratio

	Damper type	Long side (X) direction	Short side (Y) direction
Damper rigidity ratio **k** (=Kd／KF)	Hysteresis type	0.74	0.80
Damper bearing force ratio β (=Qd／Qu)	Hysteresis type	0.14	0.16
	Viscous type	0.45	0.55

Figure 10: 1760 kN type oil damper

This vibration control effect reduces the base shear coefficient during large earthquake (maximum-scale earthquake that the building may encounter within its durable term) to 0.29 maximum, and achieves reduction of the seismic force applied on the upper frame.

By providing steel dampers and oil dampers intensively on the 1st basement which can offer large elastic deformation during earthquake, much earthquake energy can be consumed dynamically on the lowest story, and damages in the structure on upper stories during earthquake can be reduced.

In addition, because dampers are not provided on other floors, less restriction is imposed on other floors, and the necessity to maintain dampers after earthquake is concentrated only on the 1st basement.

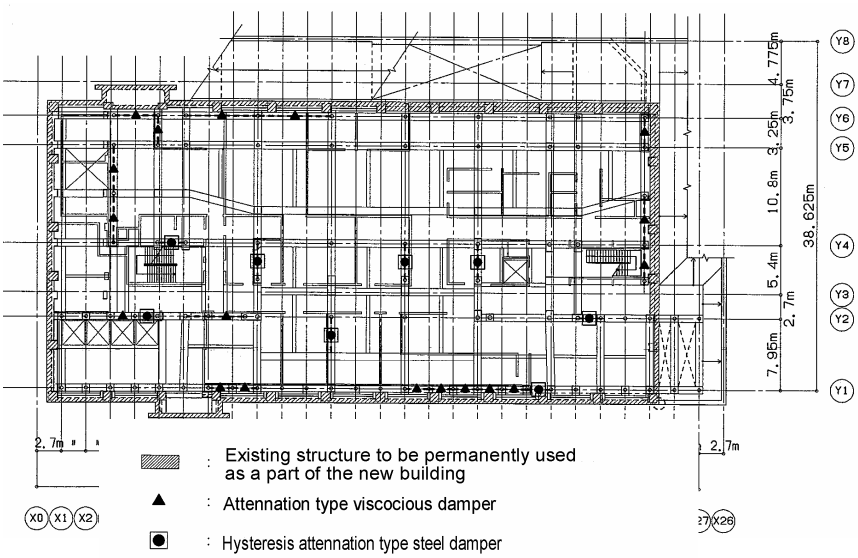

Figure 11: Floor plan of 1st basement
(intensive vibration control story)

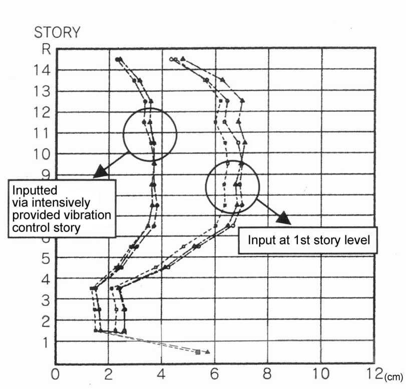

Figure 12: Vibration control effect indicated by inter-story displacement

5. REDUCTION OF EARTHQUAKE LOADS APPLIED ON OUTER CIRCUMFERENCE FRAME

CFT of 600 mm in diameter is adopted for columns in the core on the both sides of typical floors, and earthquake-resisting elements such as buckling restricting braces, shear studs and steel plate walls are intensively provided there. In this design, the core receives 70% or more of the story shear force to assure sufficient earthquake resistance even if the outer circumference frame becomes slender.

Efforts are made also to properly treat the pullout force of columns with multi-story earthquake-resisting elements which intensively receive the horizontal load. Base-pinned columns are adopted to assure sufficient resistance against the column pullout force, which is not achieved by antiseismic laminated rubber. In ball seat type steel pin bearings resistant to the maximum pullout force of 7,350 kN, the surface treated with hard chromium plating which has been used for more than 30 years in the civil engineering field is in contact with the surface treated with molybdenum disulfide baking.

The outer circumference of the building has a characteristic frame in which columns of small diameter (300 mm, centrifugally cast thick steel pipes) provided at 2,700 mm intervals are connected with beams of 250 H x 250 mm. The member cross section is determined by the technique to give the story drift of 1/100 during large earthquake as forced deformation, and decrease the bending rigidity of beams until columns and beams can keep elasticity. The non-diaphragm method is adopted for beam-to-column joints to easily absorb the difference between the beam height “400 mm” at the end in the indoor long span direction and the beam height “250 mm” in the outer circumference ridge direction.

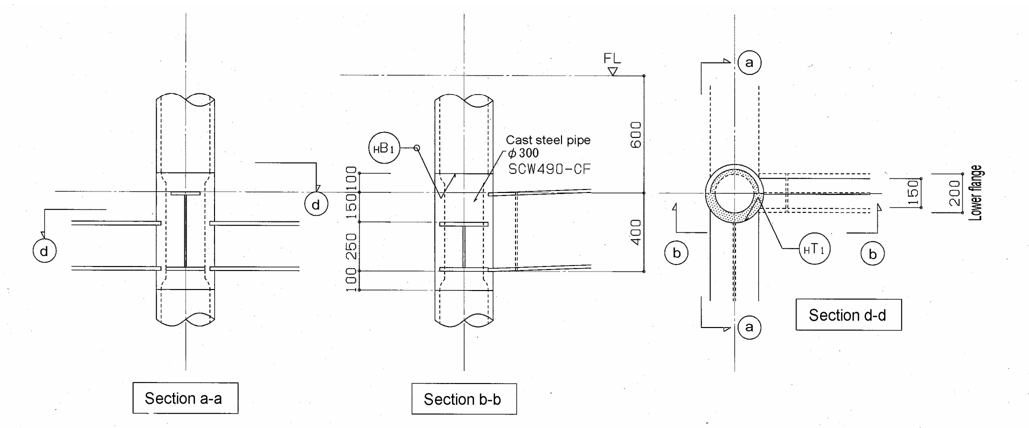

Figure 13: Joint detailed drawing

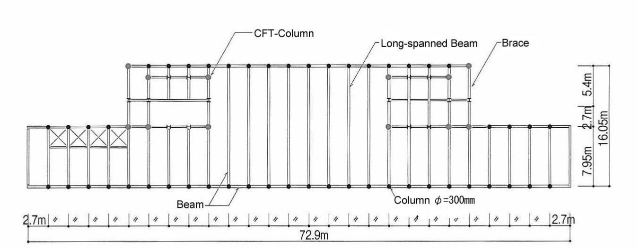

Figure 14: Typical floor framing plan

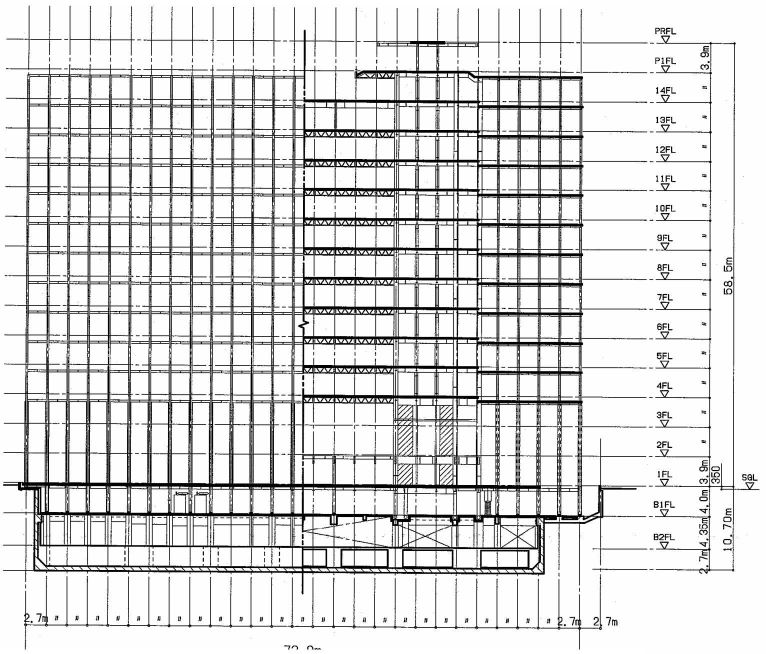

Figure 15: Framing elevation in long side direction

6. EXISTING UNDERGROUND STRUCTURE PERMANENTLY USED AS A PART OF NEW BUILDING

There was an existing building having rigid underground structure on the site. The second issue is utilizing the existing underground structure while keeping the consistency with the newly constructed above-ground portion and assuring the durability similar to the newly constructed structure.

Alignment of column positions between the existing structure and the newly constructed structure is a big restriction in the plan. Accordingly, only underground exterior walls and deck slab of the existing underground structure are left, and the newly constructed structure is integrated inside them.

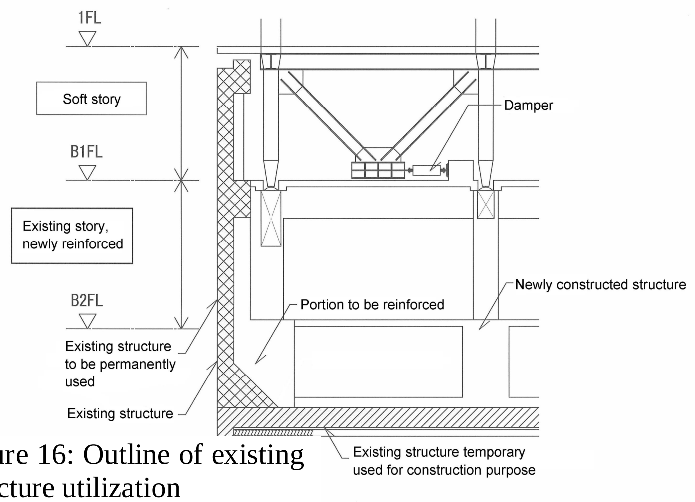

Figure 16: Outline of existing structure utilization

The underground space can be utilized more effectively in the cross-sectional direction and planar direction also by adopting intensive vibration control. Compared with column capital seismic isolation on the 1st basement, the beam height on the 1st floor is reduced, and the column cross section is compact on the 1st basement. In addition, the required structure clearance is narrow. This structure is most suitable to this building where one of important issues is construction of new structure in the limited space inside the existing underground structure.

The intensive vibration control structure contributes also to reduction of the reinforcement cost for the existing underground structure to be permanently used as a part of the new building as follows:

1) Because the column plinth is supported by pins on the 1st basement, the bending moment of individual material does not act on column capital joints on the 2nd basement. The story shear force and overturning moment acting on the whole underground structure are mitigated by the effect to reduce responses during earthquake.

2) Because the intensive vibration control story is set as the 1st basement not as the 2nd basement (lowest floor), the stress is mitigated on cantilever underground exterior walls which require edge cutting from the vibration control story.

In the existing reinforced concrete structure partially deteriorated, the durability is assured by the following methods:

- Exterior walls in contact with the soil get introduction of prestress and are reinforced from the indoor so that they do not rely on reinforcing steel outside the existing exterior walls whose durability is difficult to restore.
- The deteriorated portion in the indoor is removed, and repaired by resin injection.

Fig. 17: Construction status of existing underground exterior walls to be permanently left

Figure 18: Hysteresis type dampers on intensive vibration control story

Figure 19: Appearance of pinned column plinth

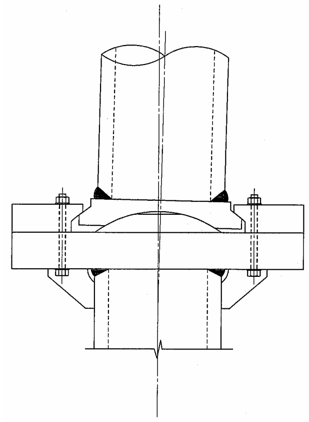

Figure 20: Cross section of ball seat type pinned column plinth

7. CONCLUSION

It is expected that the vibration control structure in which energy absorption devices such as oil dampers are effectively incorporated to improve the earthquake resistance will be used more widely in the future.
It is possible to make a structure plan in which various steel materials are combined properly to form the highly elastic main frame and improve the damper efficiency. This paper introduces a practical case of "intensive vibration control structure on the first story" as a "technique to absorb the energy efficiently and securely".

REFERENCES

[1] Taro Nakamura.(1914).Earthquake Motion Energy Absorption Equipment.*JOURNAL OF ARCHITECTURE AND BUILDING SCIENCE* **493.**
[2] Masahiro Izumi . (1986). Remarks on Several Trials. *Structure* **20,** 25-28.
[3] Hiroshi Akiyama, Toshiro Uno, Shinji Mase, Toshihiko Hirama, Takehiko Terada, Masahiro Kato and Fumio Ohtake .(1989).Fundamental Properties of First Story Energy Concentrated Steel Structure with Flexible-stiff Mixed Frames. *JOURNAL OF STRUCTURAL AND CONSTRUCTION ENGINEERING (Transactions of AIJ)* **402,** 79-97.
[4] Yoshitaka Yabe, Shinji Mase, Toshihiko Hirama, Takehiko Terada and Fumio Ohtake.(1990). Elasto-plastic Shaking Table Test of First-story Energy-Concentrated Type Multi-story Steel Frame with Flexible-stiff Mixes Structures. *JOURNAL OF STRUCTURAL AND CONSTRUCTION ENGINEERING (Transactions of AIJ).* **412,**53-65.