Seismic Isolation Retrofitting of the Main Building and Prefectural Assembly Building of the Nagano Prefectural Government:
High-Performance Seismic Isolation on Two Large-Scale Government Buildings






Satoru Nagase, Nikken Sekkei	Hiroshi Yamamoto, Nikken Sekkei	Hideyuki Hayashi, Nikken Sekkei	Yoshisato Esaka, Nikken Sekkei	Hiroaki Matsuura, Kajima Corporation	Yuji Takahashi, Shimizu Corporation

1. Introduction

Seismic isolation retrofitting was conducted on the central facilities of the prefectural government located in center-city Nagano; the Main Building of the Nagano Prefectural Government (Photograph 1, rear) and the adjacent Prefectural Assembly Building (Photograph 1, front). Table 1 provides the building summary and information on the design firm and construction firms involved.

Various challenges had to be overcome in this project, as the retrofitting design was conceived to provide the highest level of seismic isolation performance without any reinforcement of the above-ground building portions, and concurrently, the construction work needed to be performed while the buildings were in use. The construction work and design for effective seismic isolation retrofitting used in Japan will be described.

Photograph 1. Exterior of the Buildings (rear: Main Building; front: Assembly Building)

Table 1. Summary of the buildings for seismic retrofitting

Building Name	Main Nagano Prefecture Government Building	Prefectural Assembly Building
Address	Nagasaki Prefecture Nagano City Minami Nagano Habashita 692-2	
Site Area	32,122m^2	
Construction Area	3426.19 m^2	3194.74 m^2
Total Area	35,964.36 m^2	10,377.61 m^2
Structure Type	Reinforced Concrete Structure Moment Frame with Seismic Walls	Reinforced Concrete Structure (Part Steel Frame Reinforced Concrete Structure) Moment Frame with Seismic Walls
Foundation Type	Spread Foundation Strip Footing	Spread Foundation Isolated Footing
Height	46.12m	16.32m
Year of Completion	1967	1968
Original Design Firm	Naito Kenchiku	
Original Construction Firm	Taisei Corporation	
Retrofitting Design Firm	Nikken Sekkei	
Retrofitting Construction Firm	Kajima Corporation / Kitano Construction Corporation Joint Venture	Shimizu Corporation / Shimizu Corporation and Hokushin Doken Inc Joint Venture

The most important task in this project was to ensure a suitable level of seismic performance for facilities that serve as a base of disaster prevention. In selecting the retrofitting method, it was determined that strength-based reinforcement would not provide the necessary seismic resistance, and would also have a severe impact on the operations and aesthetics of the interior office space. Moreover, because no suitable alternate site during construction existed for the prefectural government facilities, all of the retrofitting work needed to be performed while the buildings remained in use. Due to these conditions, the method of seismic isolation retrofitting was ultimately selected.
In this seismic isolation retrofitting, design support was quite meticulous, with consideration for workability, maintaining functionality, and all aspects of safety during the construction period. The details are described below.

2. Project summary

2.1 Overall plan

Both buildings were constructed more than 45 years ago, and according to seismic diagnoses conducted in the past (based on General Seismic Diagnosis and Retrofitting Standards for Government Buildings and Commentary), neither had adequate seismic capacity in line to their importance factor. Therefore, it was determined necessary to reinforce them and develop specific measures. Starting at the stages of basic planning and basic design, investigation and study concerning the approach to retrofitting were conducted, with the goals of (1) ensuring a high level of seismic capacity, (2) minimizing the scope of construction and impact on office space, and (3) performing construction work while the buildings were in use. The decision to perform seismic isolation retrofitting on both buildings simultaneously was arrived. Considering the site characteristics in which a gravel layer, which is a strong support stratum emerges near the surface, and the groundwater level is shallow, intermediate layer seismic isolation at the position of pillar capitals in the basement level, with the aim of minimizing excavation work and groundwater measures, was implemented.

2.2 Summary of structural retrofitting design

The first basement level of the Main Building is used as warehouse, store, and equipment rooms. The plan involved installing the base isolation layer above the ceiling so that the space could be restored to the same uses after retrofitting (Fig. 1). Meanwhile, in the Assembly Building, abase isolation layer was constructed at the pillar capital portion of the first basement level parking garage. Consideration was also given to the number of parking spaces and the dimensions of vehicle lanes.

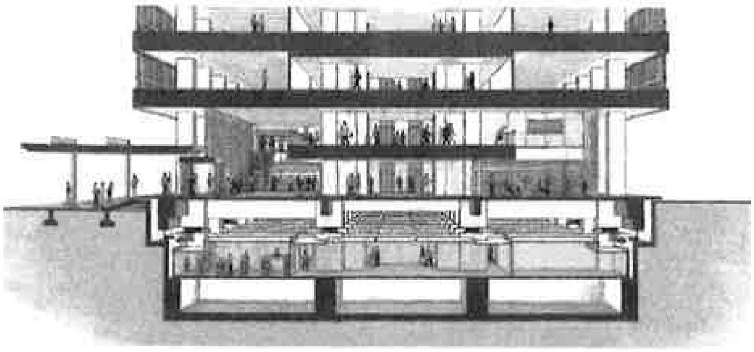


Fig. 1. Cross sectional view after seismic isolation retrofitting (lower stories of Main Building)

Unlike new construction, retrofitting plans involved various restrictions such as a small amount of clearance between buildings. Structural studies were performed to improve seismic isolation performance, and were able to provide the target seismic performance without structural reinforcement of above-ground portions. In addition, by prescribing safety measures and the necessary conditions for building functionality during the construction period, retrofitting design was developed that allowed completion of the seismic isolation work while use of the buildings could be continued (Table 2).

Table 2. Seismic design criteria

Seismic Level	Rare Earthquake	Extremely Rare Earthquake	Over Extremely Rare Earthquake
Reference Speed	25 kine	50 kine	-
Study Ground Motion	3 Kokuji Waves 3 Observed Waves	3 Kokuji Waves 3 Observed Waves 3 Site Waves	1 Kokuji Waves 1 Observed Waves 3 Site Waves
Upper Structure	Less than allowable stress	Less than yield stress	Less than yield stress
Lower Structure	Less than allowable stress		Less than yield stress
Ground Bearing Capacity	Less than allowable stress		

Seismic Isolation Floor	Response Deformation	Less than 200mm	Less than 300mm (Main Building) Less than 320mm (Assembly Building)	Less than 450mm
	Response Strain	$\gamma \leq 113\%$(Main Building) $\gamma \leq 143\%$(Assembly Building)	$\gamma \leq 170\%$(Main Building) $\gamma \leq 229\%$(Assembly Building)	$\gamma \leq 250\%$(Main Building) $\gamma \leq 322\%$(Assembly Building)
	Surface Pressure	Compression Stress: Less than allowable stress Tensile Stress: No tensile stress is experienced		

Steps were taken to improve safety with regard to non-structural building components as well, such as renovating the ceiling of the hall in the Assembly Building and replacing brick tiles on the walls of the atrium space.

2.3 Summary of equipment renovation design

The central monitoring room and electrical room on the first basement level of the Main Building were relocated to another building in advance so that work could be performed while the buildings were in use. Existing equipment was replaced and restored with great care before and after the seismic isolation work. Seismic isolation was also conducted for wiring and pipes of the electrical and mechanical systems. Reinforcement and improvement of various functions so that the building can be a disaster prevention base were also implemented, such as emergency power capacity (in-house power generation capacity for approximately 3 days), water supply (tank with approximately 4 days of drinking water), and drainage (sewage tank for approximately 7 days of storage).

3. Role of structural designers in the project

Since improving seismic capacity through seismic isolation was the most important task in this plan, structural designers served as project managers for the entire period, from the initial planning stage to work on the site and completion. At every stage of formulating and refining of the retrofitting plan and developing the detailed design, structural designers performed management functions and played a central role in various discussions with the client and other parties.

4. Key points of the seismic retrofitting design

Main Building:

Supporting a load of 12 stories including a penthouse, the pillars are subject to high maximum long-term axial force of 12,000 kN. Immediately beneath all 52 pillars, natural rubber with a diameter of 900 mm and laminated rubber isolators containing lead plugs with a diameter of 1,100 mm were placed in a well-balanced arrangement (Fig. 2, top). In addition, oil dampers were placed as separate attenuation materials. Through the effective use of viscous damping, the plan addressed the two conflicting challenges of minimizing response of the superstructure and reducing the amount of response deformation of base isolation during earthquakes, considering the site conditions where other buildings are in close proximity.

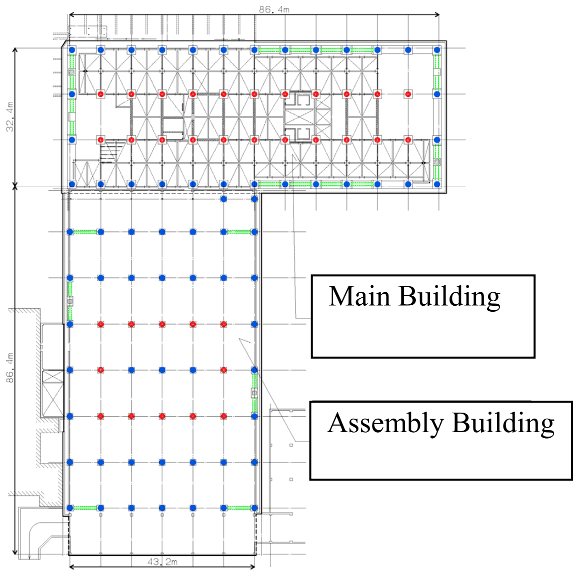
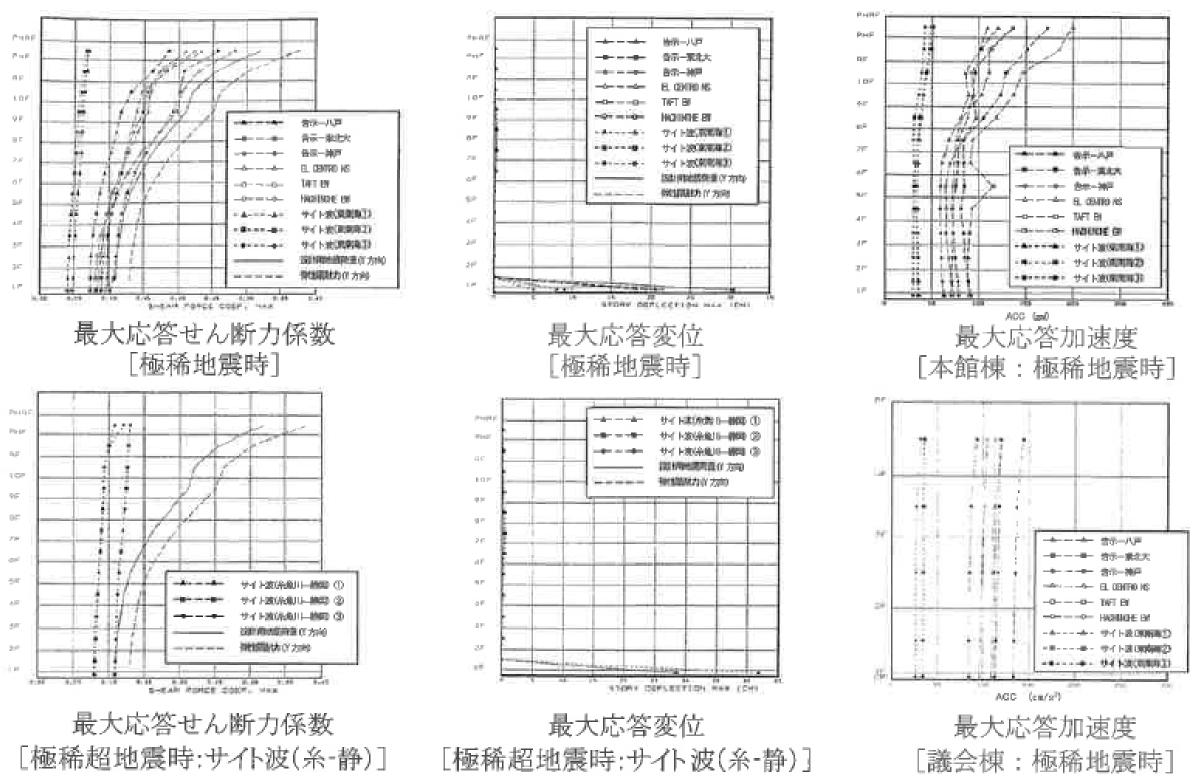


Fig. 2. Summary of seismic isolation members (top: Main Building; bottom: Assembly Building)

Assembly Building:

This building provides large spaces that are used as an assembly hall and auditorium, and the pillar axial force is not uniform throughout. Therefore, careful thought was given to the arrangement of isolators and damping materials, with the aim of constructing a base isolation layer with no torsion. By placing oil dampers on the outer periphery of the building, the plan was effective in reducing dynamic torsion. The seismic isolation members used are the same types as those of the Main Building, and the isolators are 700 mm in diameter, considering pillar axial force and the amount of seismic isolation deformation (Fig 2, bottom).

This plan made it possible to secure the necessary seismic capacity for both buildings without any reinforcement of above-ground portions. The result is high-performance seismic isolation, with the lower stories of the Main Building experiencing less than 100 gal floor response acceleration and other occupied floors experiencing less than 150 gal floor response acceleration in a strong earthquake that would occur extremely rarely (Fig. 3).



最大応答せん断力係数
[極稀地震時]

最大応答変位
[極稀地震時]

最大応答加速度
[本館棟：極稀地震時]

最大応答せん断力係数
[極稀超地震時:サイト波(糸-静)]

最大応答変位
[極稀超地震時:サイト波(糸-静)]

最大応答加速度
[議会棟：極稀地震時]

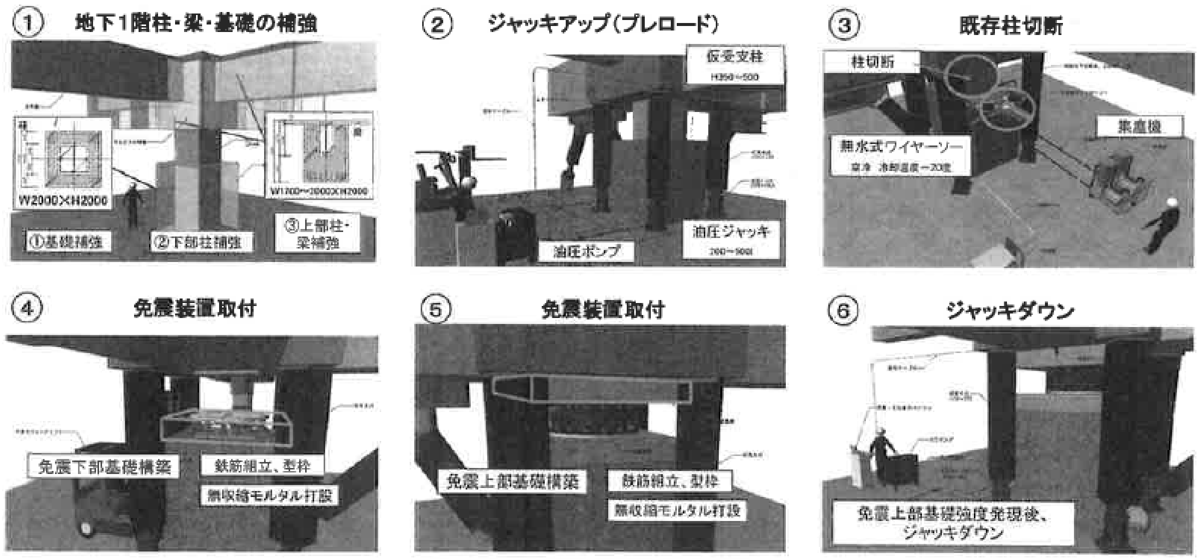
Maximum response shear force coefficient (during extremely rare earthquakes)	Maximum response displacement (during extremely rare earthquakes)	Maximum response acceleration (Main Building, during extremely rare earthquakes)
Maximum response shear force coefficient (during extremely rare earthquakes, NS Wave (Itoigawa-Shizuoka))	Maximum response displacement (during extremely rare earthquakes, NS Wave (Itoigawa-Shizuoka)	Maximum response acceleration (Assembly Building, during extremely rare earthquakes)

Fig. 3. Results of vibration response analysis (Main Building)

5. Key points of supervision

In the supervision stage after construction work began, study aspects were continued such as permanent and temporary members, replacement plans, and flow line plans while providing advice and performing checks for various retrofits.

Both buildings are important facilities with key roles in prefectural government functions. The Main Building is normally visited by about 2,000 office workers and other persons. Therefore, strict and thorough checks were conducted in cooperation with the builder with regard to safety measures in the series of work processes from frame reinforcement, jacking up (load bearing), pillar cutting, and isolator installation to jacking down (Fig. 4).



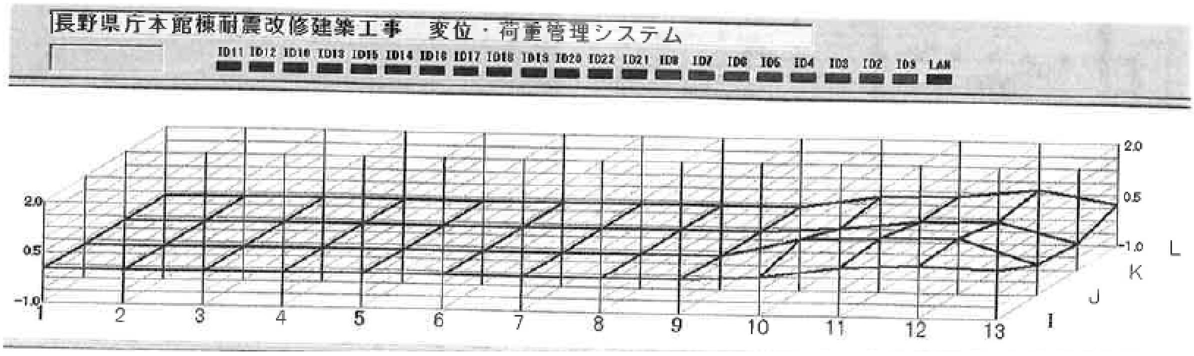
1) Pillar, beam, and foundation reinforcement on first basement level Foundation reinforcement Reinforcement of pillar bottoms Reinforcement of pillar tops and beams	2) Jacking up (pre-loading) Temporary bearing strut Pneumatic pump Pneumatic jack	3) Cutting the existing pillars Pillar cutting Waterless wire saw
4) Seismic isolator installation Construction of lower seismic isolation foundation Rebar assembly and formwork Non-shrink mortar pouring	5) Seismic isolator installation Construction of upper seismic isolation foundation Rebar assembly and formwork Non-shrink mortar pouring	6) Jacking down Jacking down after strength development in the upper seismic isolation foundation

Fig. 4. Procedure of seismic isolation retrofitting work (Main Building)

During the 30-month construction period, the prefectural assembly met 10 times in the Assembly Building, and construction work was interrupted or scaled back during those times. By means of detailed process management and coordination according to the schedule of the prefectural assembly, the retrofitting work was completed by the deadline. As a result, the Main Building and Prefectural Assembly Building of the Nagano Prefectural Government have received new life as facilities of high-quality buildings and equipment that provide high seismic isolation performance.

6. Key points of construction

Construction in the Main Building work area was performed by a joint venture of Kajima Corporation and Kitano Construction Corporation, while construction in the Assembly Building work area was handled by a joint venture of Shimizu Corporation and Hokushin Doken Inc. In order to accomplish the work while the buildings remained in use, replacement and restoration of various types of equipment occurred before and after the seismic isolation work. With the addition of preparatory work, follow-up work, and inspections, the construction period was 36 months for the Main Building and 30 months for the Assembly Building. Work on both buildings was completed at the same time in March 2014. In the seismic isolation process, from cutting the pillars to installation of the isolators, the building weight was borne by pneumatic jacks. To prevent harmful stress and deformation and ensure a smooth load transfer, 24-hour real-time monitoring was implemented for displacement control. For relative displacement in the vertical direction between adjacent pillars, measurement control was implemented at a high level of accuracy: less than 1/4,000 in general portions and less than 1/8,000 in the central core of the Main Building, which has a concentration of multi-story shear walls (Fig. 5).



Displacement and load management system for seismic retrofitting of the Nagano Prefectural Government Main Building

Fig. 5. Accuracy control in the vertical direction (Main Building)

7. Seismic isolation deformation in an earthquake of the Kamishiro Fault, Nagano Prefecture

At 10:08 PM on November 22, 2014, eight months after completion of the retrofitting project, an earthquake occurred along the Kamishiro Fault, Nagano Prefecture (seismic intensity of IV to lower V). Table 3 shows the seismic isolation deformation recorded by both buildings, and Photograph 2 shows the marking gauge records. The maximum deformation of the base isolation layer was approximately 35 to 39 mm in the Main Building and approximately 40 to 44 mm in the Assembly Building. No damage occurred inside or outside the buildings.

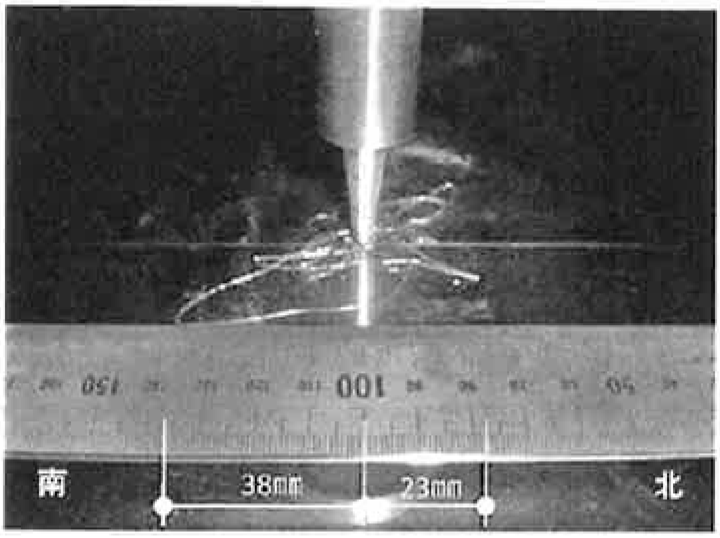
Table 3. Records of Seismic Isolation Deformation (2014.11.22)

＜本館棟＞

設置位置	南北方向		東西方向		推定最大変形（略算値）
	北	南	東	西	主方向・数値
本館棟①（西側）	18mm	31mm	23mm	18mm	南東：約 39mm
本館棟②（東側）	20mm	30mm	18mm	19mm	南東：約 35mm

＜議会棟＞

設置位置	南北方向		東西方向		推定最大変形（略算値）
	北	南	東	西	主方向・数値
議会棟①（東側）	24mm	34mm	26mm	22mm	南東：約 40mm
議会棟②（西側）	23mm	38mm	25mm	22mm	南東：約 44mm



Photograph 2. Marking gauge records (Assembly Building, 2)

8. Summary and acknowledgments

In this paper, the seismic isolation retrofitting plan for the Main Building and Prefectural Assembly Building of the Nagano Prefectural Government, key points in design and construction, and the roles played by structural designers is summarized.

We were honored to have the opportunity to work with initiative on this important project for the simultaneous seismic isolation retrofitting of two large-scale buildings which are important facilities of the Nagano Prefectural Government. We would like to express our appreciation to everyone at the Facilities & Building Planning Division, Construction Department and the Property Utilization Division, General Affairs Department of the Nagano Prefectural Government, who granted us this opportunity and provided us with their guidance and advice over a long period of time. We are also grateful to the construction companies and persons at those companies who provided cooperation in this project.