A MASONRY SCHOOL BUILDING RETROFITTED BY BASE ISOLATION TECHNOLOGY

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SUMMARY

The old masonry chapel building of Rikkyo University ,Tokyo, Japan was retrofitted by the base isolation technology. This retrofitting project is the first one in Japan for the application to the old masonry building. After the Screening of the seismic performance for sever earthquake, the seismic index (Is) is very low and retrofitting was planned. Several ideas were presented, and finally the base isolation technology was adopted in view of the construction cost and keeping the interior and exterior of the building. Before planning the detail of retrofitting method, the strength and deterioration of masonry material was examined by the loading test and the field investigation. Then, the base isolation system was decided after the nonlinear earthquake response simulation. Next, the construction work that is the most important one in the retrofitting project relating to the cost and the safety of upper building was done. Finally, the several verification tests comparing to the designed values, measuring of micro vibration , vibration test by human power and loading test were carried out. Now, a strong earthquake recording system is working.

INTRODUCTION

In the 1995 Hyogoken Nanbu Earthquake, the many buildings were severely damaged. Especially, the damage was concentrated to the buildings designed by the old seismic design code in Japan. Just after the earthquake, the law of retrofitting promotion for the existing buildings was enacted by the Japanese government. The many seismic evaluation and retrofitting projects were progressing favorably in Japan. In retrofitting construction methods, there are various type of strengthening methods; the most popular one is the newly adding the reinforced concrete wall or the steel brace inside the existing open frame. These methods have the demerits of changing the interior and exterior of buildings. Recently the base isolation technology has been used to eliminate the above demerits and to increase the high seismic performance. This paper describes the first building in Japan, which was retrofitted by the base isolation technology applying to the old historical masonry building.

OUTLINE OF THE BUILDING

Photo 1 shows the exterior and Photo 2 shows the interior of the building after the retrofitting. These two photo are almost the same as the before retrofitting. Photo 3 shows the base isolation devices under the building. This flower was newly constructed. This building was designed by Murphy & Dana Architects in USA and constructed in 1920. Rikkyo University is located inside Tokyo down Town in Japan. This is the Chapel and the historical and memorial building in university campus. Height of building is 12.63m, total area is 505.33 m^2, and one story building(partially 3 story). Longitudinal span is 27.5 m and 10.76m in transverse span. The

structure consists of masonry wall(inside reinforced concrete thin wall) and wooden roof.
The outline of building is as follows;

Name of building	: Chapel of Rikkyo University
Address	: Nishiikebukuro 3-34-1, Toshima-ku, Tokyo, Japan
Construction Year(Original)	: January, 1920
Use	: Chapel

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Total Area of Building	: 505.33m^2
Height of Building	: 12.63m
Structure	: Masonry Wall (inside: reinforced concrete thin wall), Wooden Roof
Story	: one, partially three story
Retrofitting Design	: Nikken Sekkei Ltd.
Retrofitting Construction	: Obayashi Corporation

STRUCURAL DESIGN

Base Isolation System

The base isolation system that was used in this building is the combination of the laminated natural rubber bearing and the red bar damper. Photo 3 shows this system. Figure 1 shows the location of the base isolation devices. Total numbers of the natural rubber bearing are thirteen and two kinds of 50cm and 60cm diameters are used. The axial stress to gravity load are from 35 to 112 kgf/cm^2 and vary from 11kgf/cm^2 to 186kgf/cm^2 to the strong earthquake, level 2 (50cm/s). The vertical shear coefficient 0.33 due to the vertical ground motion is considered in this axial stress. As the damper, Ten of he red bar dampers are used which are located around the natural rubber bearings. The role of these dampers is to decrease the earthquake response displacement and to converge to the small displacement after the duration of the earthquake.

Nonlinear Earthquake Response Analysis

The nonlinear earthquake response analysis was carried out to verify the earthquake resistant criteria to the severe ground motions. Figure 2 shows the restoring force characteristic of base isolation devices that are thirteen of the rubber bearings and ten of the red bar dampers. The bi-linear curve is employed. The elastic stiffness(K_1) is 130.72tf/cm and inelastic stiffness(K_2) is 10.72 tf/cm. These correspond to the periods of 0.86sec and 3.02 sec, respectively. The yield force of damper(Q_1) is 109 tf, and is 0.045 of base shear coefficient.

The three degrees of freedom system is used in the earthquake response simulation. The five ground motions, El Centro NS, Taft EW, Tokyo 24, Hachinohe NS, Art Wave 474, are used. The input level of maximum peak velocity is three, first is level 1(maximum velocity: 25cm/s), second is level 2(50cm/s), and third is extreme level(about 1.5 times of level). Table 1 shows the seismic criteria of the earthquake response for level 2. These are 25cm of maximum displacement of base isolation devices, 1/2000 radian of story drift angle of the upper structure, 0.2 of base shear coefficient of base isolation story and the upper structure. Figure 3 and figure 4 show the response displacement and shear coefficient of the transverse direction subjected to level 2 ground motion. The base isolation level’s response displacement becomes from 10cm (Tokyo 24) to 23 cm(Art Wave 474) and the upper structure’ displacement become from 1/7861 (Art Wave 474) to 1/11342 (Taft EW). These values satisfy the design criteria of Table 1. The shear coefficient of base isolation story varies from 0.08 (Tokyo 24) to 0.14(Art Wave 474). The shear coefficient of first story’s floor from 0.12 to 0.16 and ones of roof level from 0.13 to 0.18. These values also satisfy the design criteria of Table 1.

CONSTRUCTION WORK

Outline of Retrofitting Construction

Figure 5 shows the location of the base isolation devices and structural strengthening of the first floor beams. Thirteen natural rubber bearings are set under the upper structure’s wall and ten led bar dampers are planed to eliminate the unbalanced stiffness of the all base isolation devices. The existing first floor’s beams are weak and strengthened by increasing the beam’s width and depth. The clearance between the base isolation and the retaining walls supporting the surroundings ground is 50 cm.

The upper structure’s strengthen are planed as follows and shown in Figure 6;
(1) Strengthening of roof by the steel bars
(2) Connecting the lower part with the upper part of the masonry wall
(3) Connecting the lower part with the upper part of the buttress
(4) Connecting the lower building’s floor slab with the masonry wall of chapel
(5) Connecting the seat floor’s slab with the masonry wall

Construction Procedure

The important points of construction are as follows;

(1) Eliminating the irregular settlement of ground that causes the damage of upper structure

The settlement and the lateral displacement were measured during the construction work. The settlement displacement was measured always by the eight water level meters installed to the building wall. The horizontal displacement was measured by the revel meter.

(2) Earthquake resistant countermeasure during the construction work
After setting the natural rubber bearing, The steel covers around the six rubber bearings were fastened to resist the horizontal shear forced caused by the earthquake during the construction work.

The construction procedure of setting the base isolation devices are as follows and the procedure is shown in Figure 7 and the detail of base isolation device is shown in Figure 8.

(1) Breaking and removal of the existing ground level slab. Excavating around the existing foundation. Breaking and removal of the footing of the foundation
(2) Constructing the new foundation beams around the existing foundation beams. Connecting tightly the new foundation beams with the existing foundation beams by the prestressed steel bars.
(3) Excavating under the above new foundation and making the resisting pressure concrete slab. Setting the natural rubber bearings between the foundation and the pressure concrete slab.
(4) Constructing the new reinforced concrete beams and new slabs inside the building. Setting the red bar dampers. Making the retaining walls around the building.
(5) Filling the gap with the soil between the retaining wall and the surrounding ground. Constructing the scarcement around the building.

VERIFICATION TEST

The verification tests were carried out after the completion of the construction work. Three kinds of tests were done; micro vibration measuring test, human power vibration test and horizontal loading test. These three tests were carried out in the state of only rubber bearings because of the limitation of loading capacity. Very small displacement within several μm was obtained by the micro vibration measuring test. From this test, about 1.6 sec of natural period was obtained. Photo 4 shows the human power vibration test. The vibration was caused by the human power. Figure 9 shows the result of this test for the transverse direction. About 300μm of displacement and 1.8 sec natural period were measured and about 8 % damping coefficient was also obtained. The horizontal loading test is shown in Photo 5. The two static oil jacks (total capacity 50tf) are installed between the foundation of the just above of rubber bearings and the retaining wall. Figure 10 shows the horizontal shear force and the horizontal displacement relationship. The predicted curve from the each rubber test result measured just after fabrication is also shown in this figure. These both curves show the good similarity. 30 mm is the maximum displacement that is the maximum capacity of oil jacks. Figure 11 shows the summary results of these three test comparing to the predicted values. The relationships between the stiffness and the horizontal displacement are discussed. From this figure, the dynamic property of rubber bearings in the wide range of displacement is obtained and is confirmed to be coinciding with the predicted values.

CONCLUSIONS

A historical masonry building that was retrofitted by the base isolation technology was discussed in this paper. It was confirmed that the base isolation technology is the feasible retrofitting method in order to conquer the limitation of the weak strength and the architectural feature of the building. The strong accelerometer that was installed at the ground level and the first story floor level is working.

ACKNOWLEGEMENT

This project .has been reviewed by the Rikkyo University Retrofitting Committee (chairman: Professor Okada, Shibaura Institute of Technology) that was organized in the Japan Building Disaster Prevention Association. In the process of making the paper, I would like to appreciate to the help of Mr. Sugiyama, K. and Mr. Nakamura, M., Obayashi Technical Research Institute.

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2. Tsuneki, Y., Tojo, K., Warashina, M. and Koyanagi, M. (1999)“The Base Isolation Retrofitting Construction Work of The Chapel of the Rikkyo University ”, Concrete Journal, Vol.37, No.4, Japan Concrete Institute, 1999.4.

Photo. 1 Exterior of Chapel Building

Photo. 2 Interior of Chapel Building

Photo. 3 Base Isolation Devices

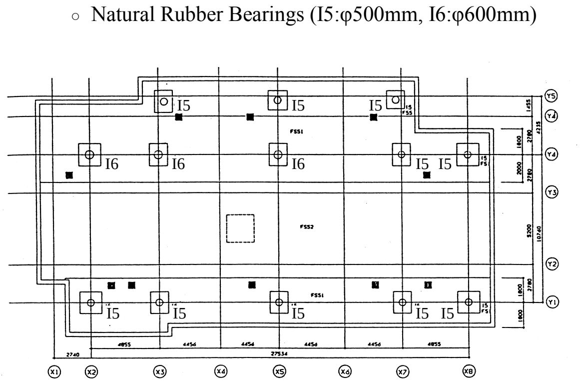


Figure 1 Location of Base Isolation Devices

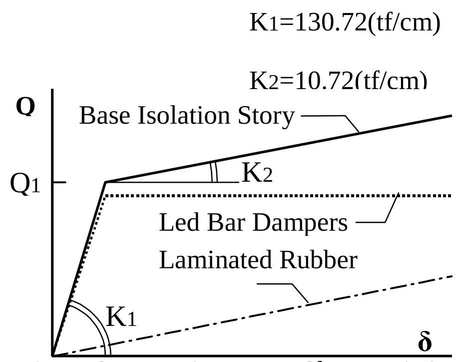


Figure 2 Restoring Force Characteristics of Base Isolation Story

Table 1 Design Criteria of Earthquake Response (Input Level : 50 cm/s)

Base Isolation Story Level	Maximum Drift Displacement	Less Than
	Maximum Shear Force Coeffient	Less Than
Upper Structure Level	Maximum Drift Angle	Less Than
	Maximum Shear Force Coeffient	Less Than

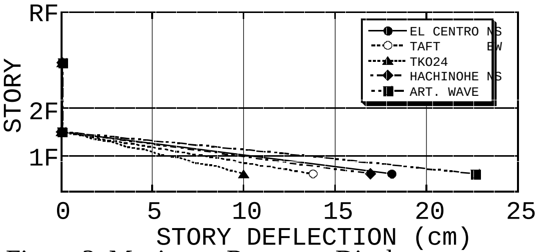


Figure 3 Maximum Response Displacement (50 cm/s Input, Longitudinal Direction)

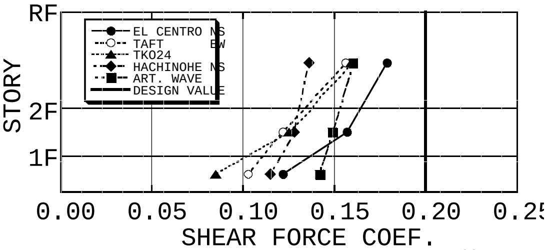


Figure 4 Maximum Shear Force Coefficient (50 cm/s Input, Longitudinal Direction)

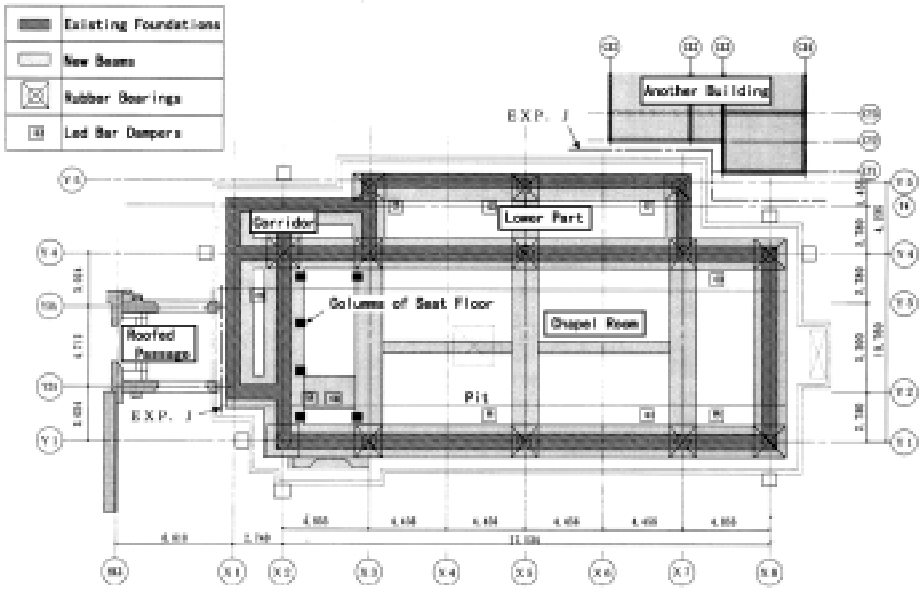


Figure 5 Location of Strengthened Beams and Base Isolation Devices

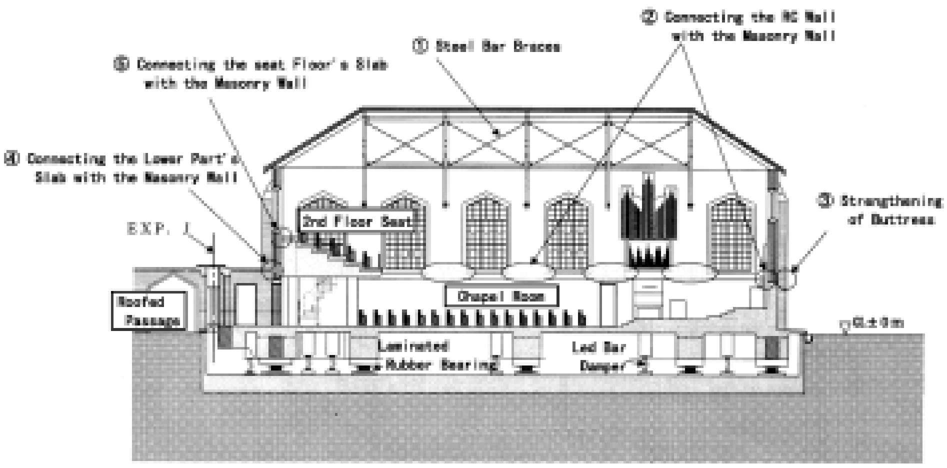


Figure 6(a) Section (Y2A)

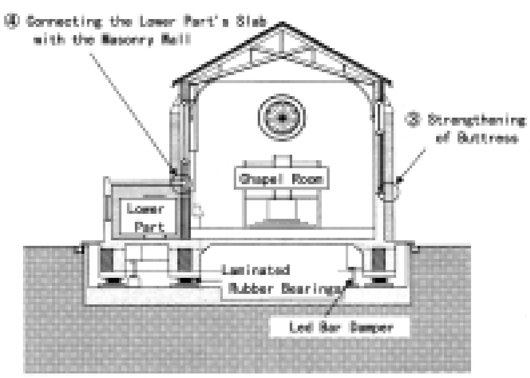


Figure 6(b) Section (X5)

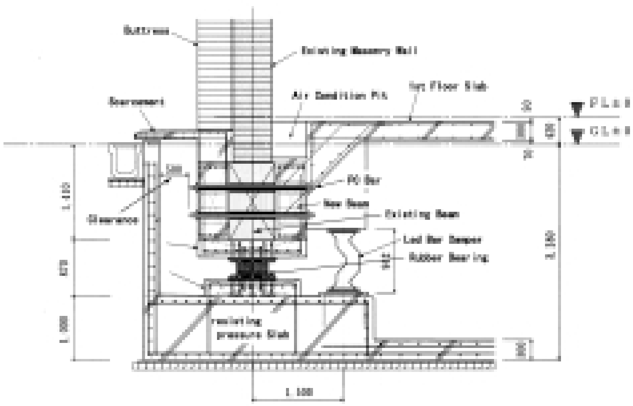


Figure 8 Detail of Base Isolation Devices

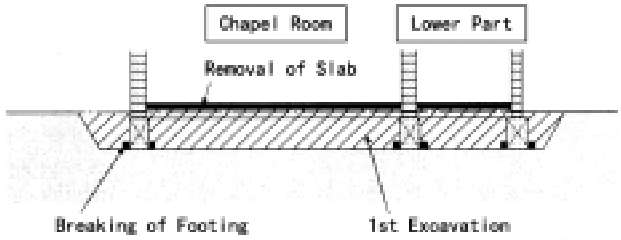
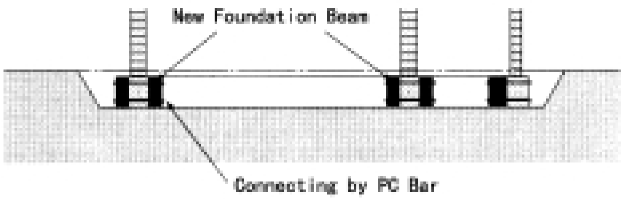
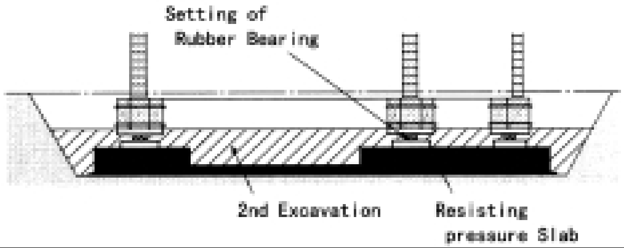
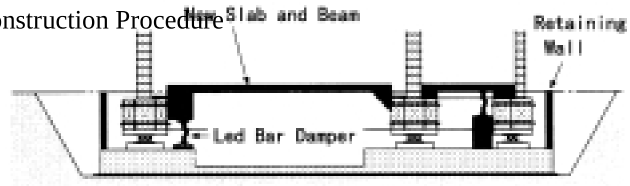
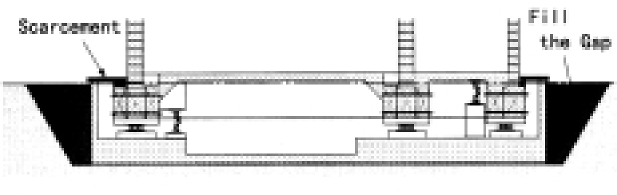
(1) Breaking and removal of the existing ground Level slab. Excavating around the existing foundation. Breaking and removal of the footing of the foundation.	
(2) Constructing the new foundation beams around the existing foundation beams. Connecting tightly the new foundation beams with the existing foundation beams by the pre-stressed steel bars.	
(3) Excavating under above new foundation beams and making the resisting pressure concrete slab. Setting the natural rubber bearings between the foundation and the pressure concrete slab.	
(4) Constructing the new reinforced concrete beams and new slabs inside the building. Setting the led bar dampers around the building.	
(5) Filling the gap with the soil between the retaining wall and the surrounding ground. Constructing the scarcement around the building.	

Figure 7 Construction Procedure

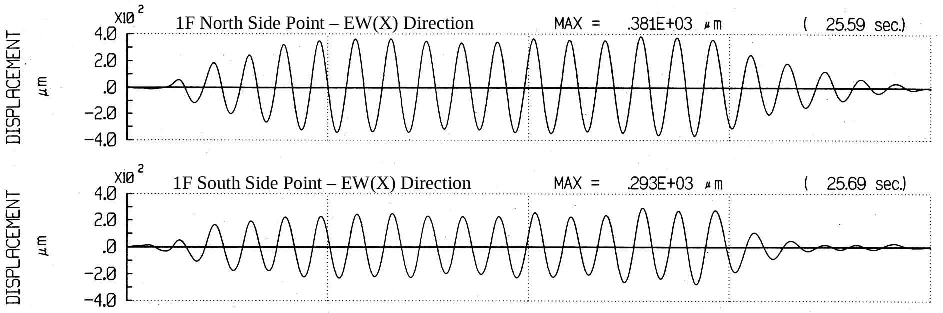


Figure 9 Human Power Vibration Test (Transverse Direction)

Photo. 4 Human Power Vibration Test

Photo. 5 Static Loading Test By Using Oil Jack

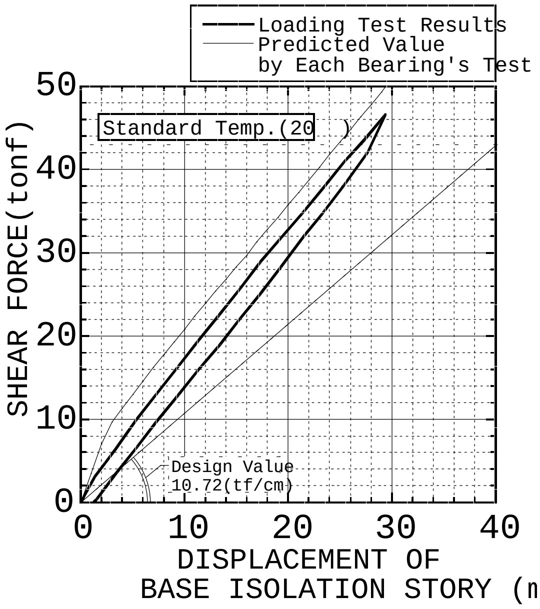


Figure 10 Shear Force – Base Isolation Story's Displacement Curve

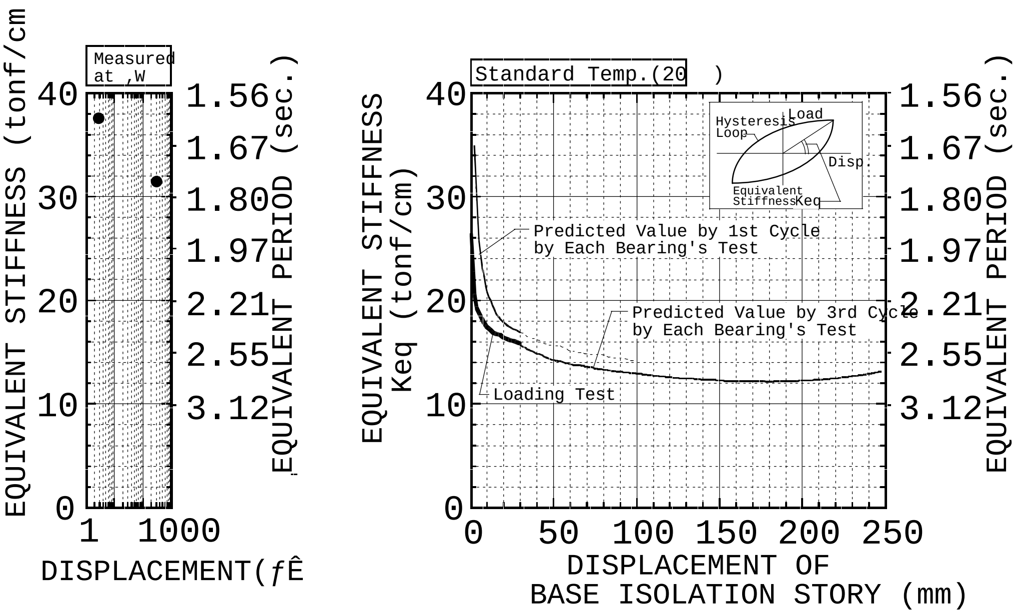


Figure 11 Summary of Vibration Tests