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TEST OF AN INFLATED RUBBER CYLINDRICAL ISOLATOR

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ABSTRACT

Base isolation approachs can reduce the responses of isolated buildings during earthquakes. To lower the cost of isolators will make the base isolation approach more practible and easy to popularise. In this paper, the design procedure and the tests of the inflated rubber cylindrical isolator are introduced. Property and advantages of this type of isolators are described.

KEYWORDS

Base Isolation; Seismic Isolation; Rubber Isolator; Passive control of structures.

INTRODUCTION

Base isolation approachs have been used in many buildings and got good result during big earthquakes.[1, 2,] These facts verified the base isolation approachs are successful to protect buildings from earthquakes. All of these buildings are isolated by steel plates laminated rubber bearings. Though, there are many other types of base isolation approachs, some of them have not been applied, or experienced in big earthquakes.[3, 4] Namely, only the laminated rubber pads isolators are used in true buildings and experienced in earthquakes. The earthquakes records, buildings responses records and ground motion records together, verified that this kind of isolator is good for protecting the buildings from earthquakes. Although there are advantages and the good performance of this type of isolator, but its cost is so expensive that some designers would not like to adopt it in building aseismic design, particularly, in the low cost buildings. Therefore, at present time, to lower the cost of isolator is a trend for popularization of this technique in the world , especially in developing countries. Another problem is the durability of these approachs. Generally, the life-span of a building is more than one hundred years. But the life-spans of some isolators installed under buildings are much less than one hundred years. For this reason, isolators have to be replaced during the service life time of the supported buildings. Untill now, there have not any isolated buildings experienced the replacement of the isolators. Some engineers suggested when isolators need to be replaced, this building might be lifted up by hydraulic jacks to pull out the used isolators and insert new ones in place. However, no building has been lifted up for replacement of isolators. Perhaps, for some brittle masonry buildings, cracks might be created during the un-evenly lifting when many jacks under this brittle building operated un-synchronmatically. More over, some reinforced concrete beams might be broken and fell down due to the un-equal lifting displacements, and the end moments at these beams might be changed from negative to positive. I am afraid, this problem could have been over-estimated. I wish it were not true. Nevertheless, an isolator which can be replaced easily and safely is needed. In this paper, a new type base isolation approach is introduced with low cost effect and easy replacement of the isolator.

INFLATED CYLINDRICAL RUBBER ISOLATOR

Firstly, make a short section of rubber pipe with fiber reinforced in longitudinal direction. Seal the two ends by rubber plates. Out of the circumference, wounds the pipe by high-strength spiral steel wire to strengthen the pipe for resisting the high inner pressure of inflated liquid. Covered this rubber isolator by two steel plates for preparing placed on the foundation for carrying the building.

For carry the building, the isolators have to have the ability for carrying a heavy vertical load, that is to say, the isolator have to be inflated by high-pressure liquid. Now, suggest a typical isolator, it can carry a vertical load **W = 100** tons, and its inner dimeter **D = 40** cm. The inflated liquid pressure **p** :

$$p=W/(\pi \cdot D^2/4)=100000/(\pi \cdot 40^2/4)=80 \text{ kg/cm}^2$$

The hoop tension of the spiral steel wounded on the circumference of this rubber pipe is :

$$T = p \cdot (D/2) = 80 \cdot (40/2) = 1600 \text{ kg/cm}$$

The cross-sectional area of the high-strength spiral steel wire should be:

$$A = T/[\sigma] = 1600 \cdot 100/4000 = 40 \text{ mm}^2/\text{cm}$$

it indicates that the spiral steel should be large enough. To satisfy this amount of steel area, **φ5** mm high-strength steel wire wounded circle by circle closely and tightly around the pipe will provide the steel area of **A = 39.27** mm²/cm. If select **φ 2.5** mm steel wire for taking the hoop tension, it should be wounded two plays and wounded circle by circle closely.

In the model for testing, the inner diameter is D_i **= 12.5** cm, and outer diameter is D_o**=16** cm. The inflated inner pressure is the same as suggested above: **p = 80** kg/cm² . Its vertical bearing capacity is :

$$W_m = p \cdot (\pi \cdot D_i^2/4) = 80 \cdot (\pi \cdot 12.5^2/4) = 9818 \text{ kg} = 9.818 \text{ tons}$$

The hoop tension $T_m = 80 \cdot (D_i/2) = 500$ **kg/cm**

The cross sectional area of steel wire needed :

$$A_{sm} = T_m/[\sigma] = 12.5 \text{ mm}^2/\text{cm}$$

Using **φ2** mm, and spacing **2.5** cm , provides **12.57** mm² /cm.

In this case, the strain of this steel wire acted by the hoop tension :

$$\varepsilon_{sm} = [\sigma] / E_s = 4000/(2.1 \cdot 10^6) = 1893 \cdot 10^{-6}$$

The elongation of the spiral steel wire may cause a shortenning of the height of the cylindrical rubber pipe. Neglect the volume change of the rubber material of the pipe wall, and the volume if the inflated liquid cannot be changed in compression, therefore, the shortenning of the height of this cylindrical pipe ΔH :

$$\Delta H = -2 \cdot (H \cdot \Delta D_i / D_i) = -2 \cdot \varepsilon_{sm} = 3786 \cdot 10^{-6}$$

The vertical stiffness of this isolator E_v :

$$E_v = W_m / \Delta H = 9.818/(3786 \cdot 10^{-6}) = 324.2 \text{ T/cm}$$

It is strong enough to carry the building vertical load, and make the supported building stable.

The horizontal stiffness of this isolator under a shearing force is the shearing rigidity of the rubber wall of this pipe, (the contained liquid cannot resist any shearing force). The cross sectional area of the rubber wall :

$$A_{mr} = \pi \cdot (D_0^2 - D_i^2)/4 = 78.34 \text{ cm}^2$$

The shearing stiffness of this isolator :

$$E_h = 0.979 \text{ T/cm}$$

It is soft in the horizontal direction. It may reduce the responses of the building during horizontal earthquake shakings. This character satisfy the condition of isolation approach for protecting buildings from earthquakes. This model is shown in Photo 1, and its drawing is shown in Fig. 1.

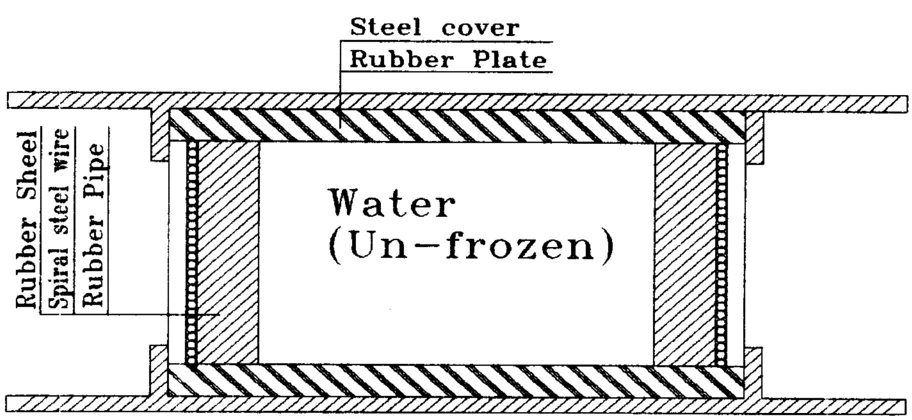

Fig1. Sectim of the Inflated Cylindrlcal Rubber Pipe Isolator

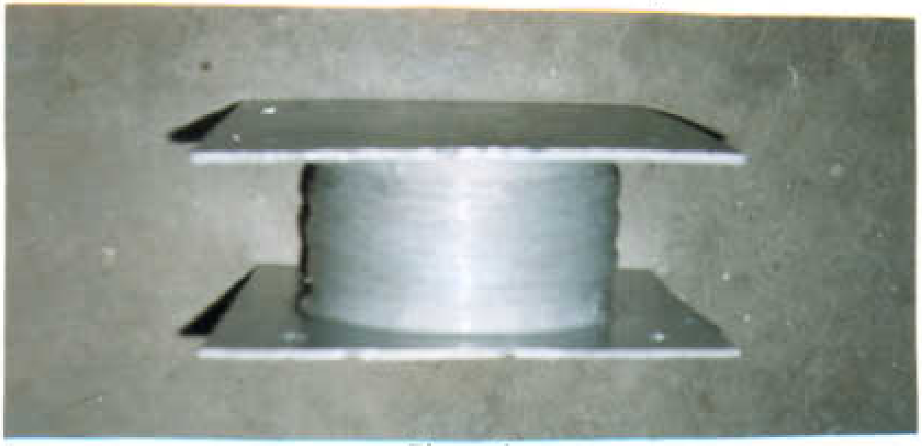

Photo. 1

Otherwise, this kind of isolator needs less amount of rubber material, and it is easy to be manufactured, Therefore its cost will be lower than other types of rubber isolators.

TEST OF THIS ISOLATOR

(1) Vertical Loading Test.

Put an inflated rubber cylindrical isolator on an universal testing machine,(photo. 2) apply a vertical load, the load-deformation curve is obtained. (Fig. 2)

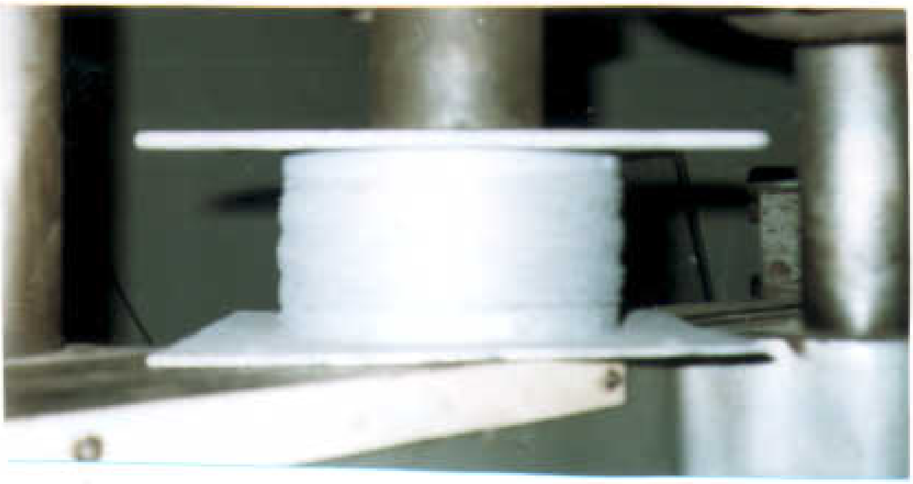

Photo. 2

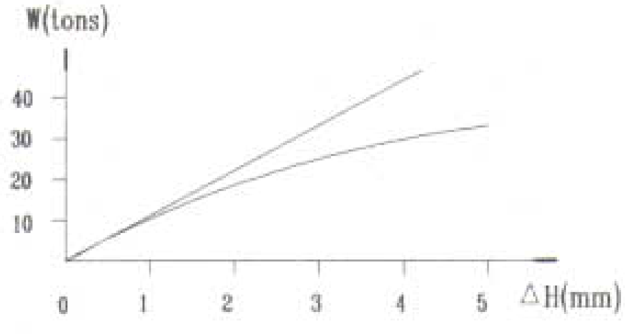

Fig. 2 Load-Deformation Curve of Isolator acted by vertical load.

The appearence modulus of elasticityin vertical direction **E_v = 98** ton/cm.

(2) Shearing Force Test

Set an isolator on an universal testing machine, and placed many round balls under this isolator for free sliding. Apply a vertical load **10** tons, acts a pair of horizontal shearing force **P**, and measure the shearing displacements by a micrometer, (Fig.3) the shearing force-displacement curve (Fig.4) is obtained.

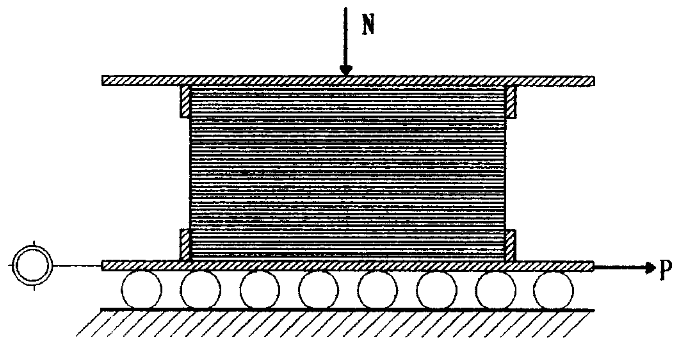

Fig.3 Sketch of shearing test Arrangement

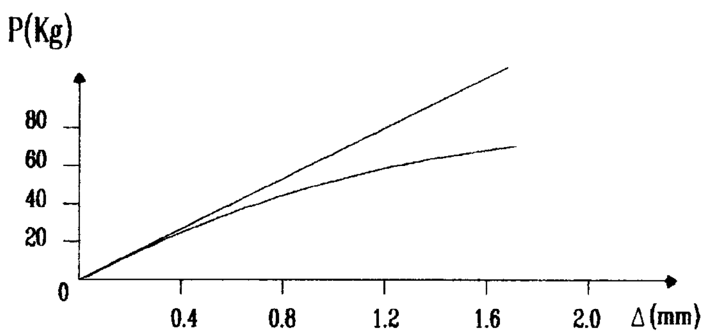

Fig.4 Shear Force - Deformation Curve

The appearance shearing modulus of elasticity of this isolator is **E_h =0.66** ton/cm.

CONCLUSION

Obviously, the inflated cylindrical rubber isolator has a good characters used as in the base isolation approach for protecting building from earthquakes. A good isolator has to be:

(1) Effective in isolating ground shakings;
(2) Low cost;
(3) easy to be made and easy to be set in construction;
(4) Durable and easy to be replaced an used isolator by a new one.

All of these four items are satisfied by the inflated cylindrical rubber isolator. Its stiffness in vertical direction is strong enough to carry a large vertical load with small vertical deformation. It makes the supporting building stable when using proper amount of this kind of isolators. On the other hand, in horizontal direction, it is soft, and can isolate the horizontal ground shakings well. It can reduce the horizontal responses of the isolated building during earthquakes. This property can protect the supporting building from earthquakes.

Owing to the rubber material used for making this isolator is not too much, and the technique for making this isolator is not too hard, therefore the cost will be low. When the cost of the isolator is lowered, the base isolation approachs will be developed more easily and spread this approach more broadly.

Although the procedure for making this kind of isolator is a little more complicate than others, but there is no any hard to making a fiber reinforced pipe, wound the circuference with steel wire, seal the ends, etc.. In the construction place, it will be set on the foundation, and inflate it with pneumatic liquid(non-frozen liquid) till designed pressure is obtained. That is ready. Whenever an old one should be replaced, deflate the liquid, and replace a new isolator in place, inflate liquid to designed pressure is all we needed. If a small tube connected all isolators under a building to make the inflated liquid pressure unified, then the load distribution on each foundation will be the same as designed. Even there were uneven settlements of some foundations, the load distribution would maintain the same as designed, because the liquid would flow through the tube to adjust the pressure automatically in each isolator. To keep this building untilting, several auxiliary isolators placed at corners, and do not connected by small tube to the main isolators to support the increment load at that corner when the building has a little tilting.

ACKNOWLEDGEMENT

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REFERENCES

[1] Kelly, J. M.:"Progress and Projects in Base Isolation", Proc., Seminar on Base Isolation and Passive Energy Dissipation, March 1986. San Francisco, U. S. A.

[2] "Base Isolated Buildings in Japan, Complete Guide to BCJ-M1(1985) ~ BCJ-M65(1991)". Research Committee of Architectural Institute of Japan for Base-Isolated Structures.

[3] Takayama, M. et al:"Development of New Isolators" Proc., International Workshop on Recent Development in Base-Isolation Techniques for Buildings. pp.199-210 1992. Tokyo, JAPAN.

[4] Li, L., et al:"Seismic Isolation Techniques for High-rise Buildings" Proc., 2nd Conference on Tall Buildings in Seismic Regions. pp. 251-260. 1991. Los Angeles, U. S. A.