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BEHAVIOR ANALYSIS AND APPLICATION RESEARCH FOR TREATED ASPHALT-FIBRE SEISMIC ISOLATION CUSHION

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SUMMARY

In recent years the treated asphalt-fibre seismic isolation cushion got into trial application in the design of base isolation system of two masonry buildings in Hangzhou, China. Its good economy, safety and moderate isolation effect arouse the interest of engineers. In this paper a brief introduction to one of these buildings is provided. First from the shear-compression test of the isolation cushion, the hysteresis loops are analyzed, the equivalent stiffness model with equivalent damping ratio is presented to simulate the physical behavior of the cushion, and then a scaled-down model experimental result is analyzed, the parameters of hysteresis relationship are verified by comparison between the test result and one DOF dynamic analysis to the experimental model. Based on this reasonable hysteresis relationship, a two DOF dynamic response analysis is performed to the previous introduced building. This paper provides isolation effect evaluations to this kind of isolation cushion, also from the design experience, some recommendations to the using of this kind of cushion are presented.

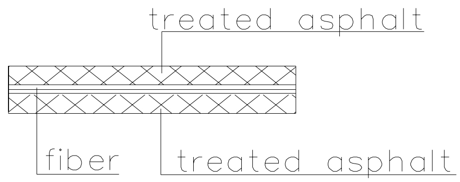
INTRODUCTION

In the recent ten years before 2001,more than 300 buildings in China were built with base isolation, which isolators mostly were lead-cored laminated steel-plate rubber bearings. The isolation effect of this kind of isolator is good, but it has some problems:

(1) It's a point support system, which has more risk when the foundation has uneven settlement or when the seismic displacement response is too large, or when it exposes to fire hazard.

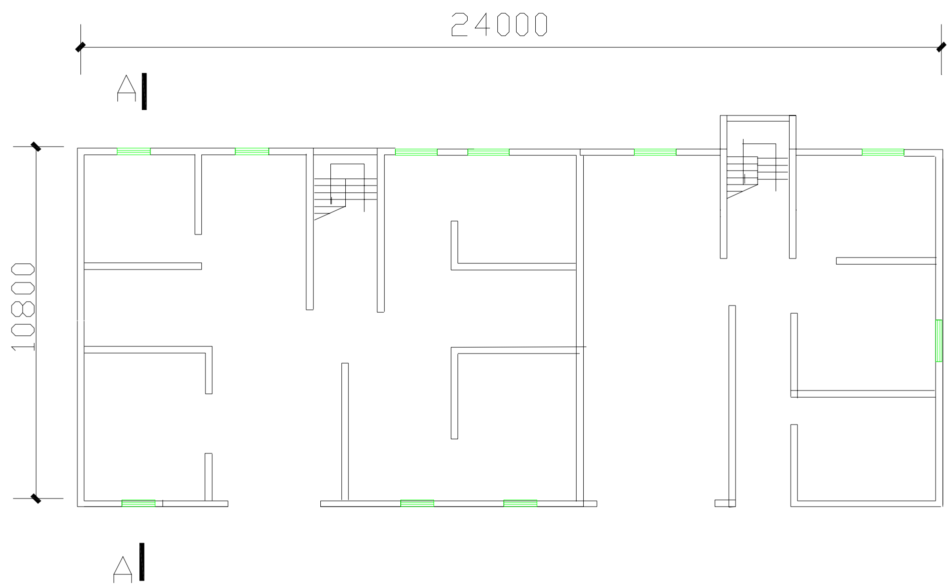
(2) It's expensive. In medium earthquake hazard regions buildings isolated with lead-cored laminated steel-plate rubber bearings have considerably higher construction cost than these buildings designed with traditional seismic resistant structure.

In 1999 a new kind of base isolator was invented (Chinese Patent Number ZL99202381.5) in Hangzhou, China. We called it BS cushion, which is ' Treated Asphalt-Fiber Seismic Base Isolation Cushion". The advantage of this kind of isolator is its low cost; safety while its isolation effect is moderate. Here is the structure of BS cushion.



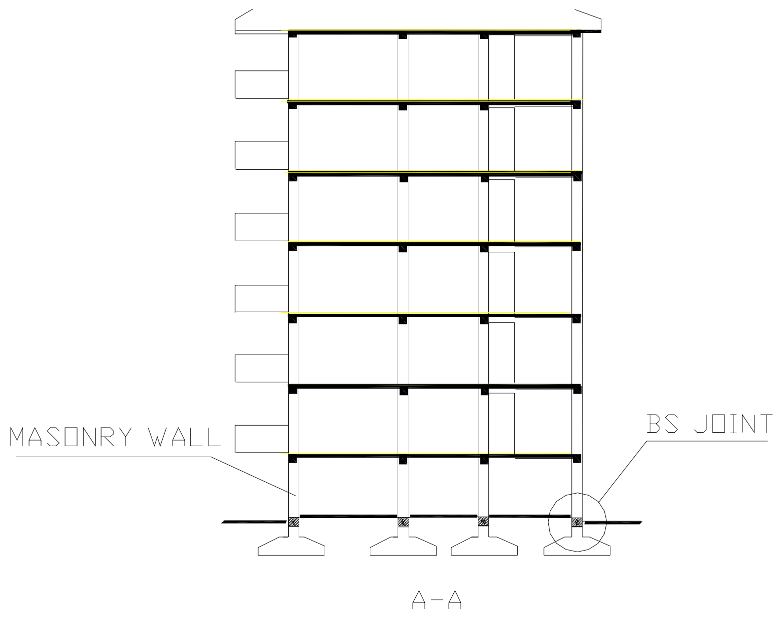
The invention of BS cushion took the reminder of laminated steel-plate rubber bearing. Taking fiber and treated asphalt over steel-plate and rubber respectively, is the basic philosophy of BS cushion.

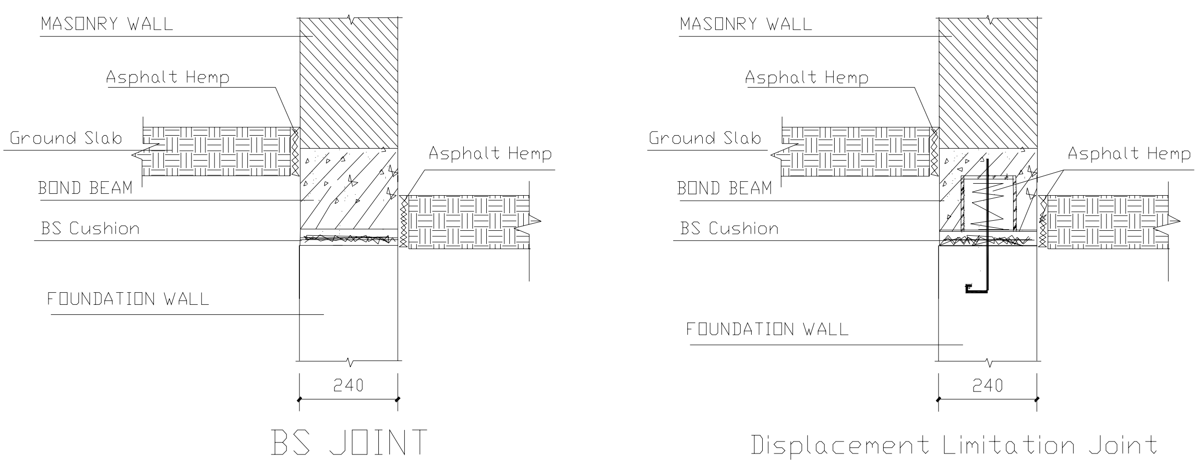
Before 2001 two 7-storey masonry-concrete residential trial buildings isolated with BS cushion were built in Hangzhou, China. One is isolated by replaced some depth of base soil under mattress foundation with alternative setting of 4 layers of BS cushion and 4 layers of sand. The fundamental period of this building is elongated from 0.3 second to 1 second. 0.3s is tested from a similar building and 1s is tested from this building. Due to the huge area application of BS cushion in this project, the construction cost of this building rose considerably. The author of this paper designed another building, and was directed by BS cushion main inventor, G.Z. Qian. In this project only one layer of 20mm thickness of BS cushion was used to separate all the bearing walls and strip foundation walls. Due to the small area application of BS cushion in this project, the construction cost of this building didn't rise compared to un-isolated buildings. Here the project description is provided as below:



FIRST FLOOR PLAN (BS Cushion Layout)

Ground floor is for bicycle storages, asphalt hemp gap is provided between bearing walls and solid ground slab. 74 displacement limitation joints are distributed to avoid local excessive displacement. The total mass above the BS cushion of this building is 2427t (iz. 13.6 kip.s^2/in). As we calculated the fundamental period for the building with program TAT, under the un-isolated condition, the fundamental period is 0.2 second. The total used area of BS cushion is 48 m^2. The average compression in BS cushion is 0.5 Mpa.





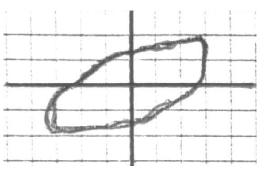
At that time, we were lack of numerical theory study to the behavior of BS cushion and dynamic response analysis under a certain earthquake excitation. The design of this trial building was under the assumption that the building was a rigid body, thus the isolated building could be modeled as one degree of freedom (DOF) K-M-C system which has a same damping ratio as the BS cushion has (ξ=30%). As the

Chinese seismic design spectrum, a ξ=30% one DOF K-M-C system has 50% less of acceleration response than that of un-isolated buildings (ξ=5%).

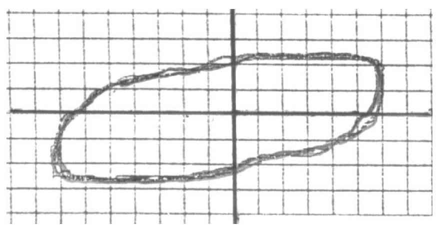
Because this evaluation of isolation effectiveness was based on an unreliable assumption, even the author himself doubted the isolation effect of this building at that time. In the next two years, rational studies were continued. The purpose of this paper is to calculate a believable isolation effectiveness of this trial building on the basis of a reasonably established theory.

BEHAVIOR OF BS CUSHION

In 2000 cyclic shear-compression test procedures were designed in Huazhong University of Science and Technology (China) to measure the load-displacement loops of BS cushion during the horizontal stroke of ±10mm and ±20mm at a cyclic frequency of 0.2Hz, while an axial load compression of 1Mpa and 2 Mpa representing structural weight was applied. Here are the dynamic force-displacement hysteretic loops obtained from the test of BS cushion bearing having the size of 200mm diameter, 16mm thickness, and 0.0314-m2 areas.



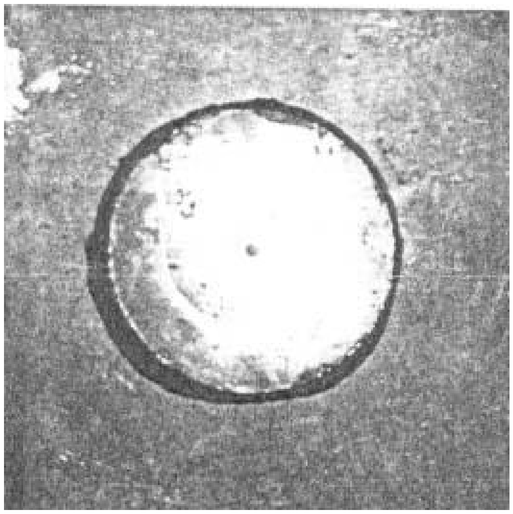
hysteresis loop
1Mpa compression
0.2Hz
±10mm stroke



hysteresis loop
1Mpa compression
0.2Hz
±20mm stroke

Horizontal Shear Displacement	Equivalent stiffness KN/mm	Equivalent damping ratio ζ
10mm	0.46	33%
20mm	0.31	44%

Vertical stiffness is 250KN/mm, vertical limit compression is 216KN. Under 1Mpa and 2Mpa compression, the tested bearings have stability under limited cycles. Damping is high.

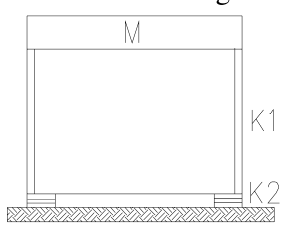


Picture of BS cushion bearing after test

The equivalent stiffness of BS cushion bearing was also verified by a scaled-down model experiment in Zhejiang University, China.

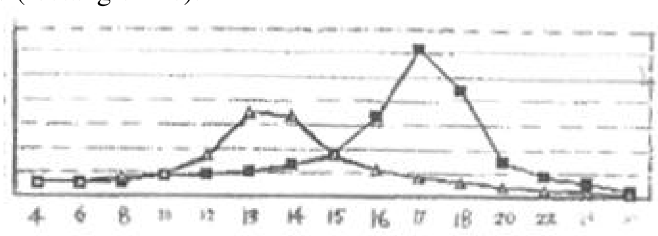
This experiment was demonstrated by a one-story 4 columns frame:

Using 50cmx50cmx0.8cm plexiglass plate to simulate the floor and the base slab of a frame, using 4-Φ6mm rebar to simulate the columns of the frame, binding some mass of steel plate to the floor to simulate the dead load, on a small shaking table, we did the Frequency Response Function experiment without BS cushion and with BS cushion respectively. BS cushion bearings are 4-5cmx5cmx2cm, stuck to each underside corner of base slab and shaking table.



In this model, the mass is 7.51kg, stiffness is K_1=85.6KN/m, and its calculated fundamental period without BS cushion is:

$T_1=2 \bullet 3.14 \bullet \sqrt{0.0075/85.6}$ =0.059s, frequency f_1=17Hz. This can be verified from the experiment result below (rectangle line):



Triangle line is for isolated frame;
Rectangle line is for un-isolated frame.

From this result we also can see the composite fundamental frequency of isolated frame is f=13.5Hz, T=0.074s, the composite stiffness K can be calculated as: $K=4\bullet 3.14^2\bullet M / T^2$ =54KN/m. Assuming the BS cushion stiffness is K_2, then

$K=K_1\bullet K_2 / (K_1+K_2)$

$54(85.6+K_2)=85.6\ K_2$

K_2=143 KN/m -----------(1)

If we estimate K_2 for the BS cushion bearings from the shear-compression test result, then

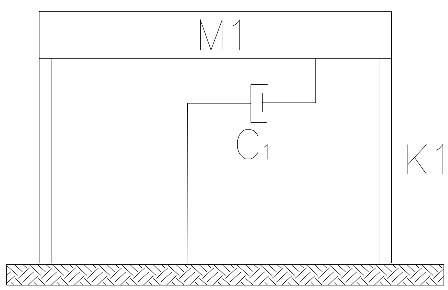
$K_2=0.46\text{x}0.1\text{x}0.1\ m^2 / (0.25\text{x}3.14\text{x}0.2^2\ m^2)$=148KN/m -----------(2)

The values in equation (1) and (2) are almost equal. This verified the equivalent stiffness of BS cushion.

It is also noticeable that the compression in BS cushion of this experiment is only 0.0075Mpa. Compression doesn't affect the stiffness when the compression is below 2 Mpa.

MODELING AND ISOLATION EFFECT EVALUATION

The concerned trial building without isolation can be modeled as 1 DOF of K-M-C system. For the fundamental modal shape, we can consider 75% of total mass as the lumped effective mass, iz. M_1=2427tx0.75=1820t (iz. 10.2 kip.s^2/in)



model without BS cushion

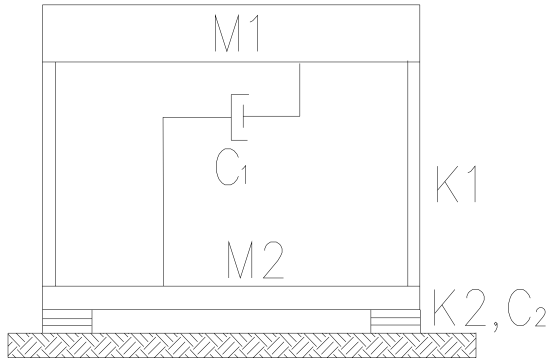
T_1 has been known to be 0.2s, then K_1 can be calculated as:

$K_1=4M_1\bullet 3.14^2 / T_1^2$ =10000kips/in. Assuming damping ratio ξ_1=5%,

then damping constant $C_1=\xi_1\bullet 4\bullet M_1\bullet 3.14 / T_1$=32 kip.s/in

To evaluate the frame elastic force peak response under El Centro 1940 time history ground motion with 1.0g of peak acceleration, the program NONLIN can be employed to perform the calculation. This program gives the frame elastic force peak value to be 7328 kips. (NONLIN is the property of the Federal Emergency Management Agency, USA. It is free from copyright restrictions and is available by download from website)

The building with BS isolation can be modeled as 2-DOF K-M-C system. For the fundamental mode shape, in addition to M_1=10.2 kip.s^2/in, we can consider 25% of total mass as the lumped effective mass to the second DOF, iz. M_2=3.4 kip.s^2/in



model with BS cushion

K_2=(48 m^2/0.0314 m^2)x0.46KN/mm=3871 kips/in ,

damping ratio ξ_2=33%, damping constant C_2 can be calculated as below:

$M=M_1+M_2$=13.6 kip.s^2/in $K=K_1 \bullet K_2/(K_1+K_2)$=10000•3871/(10000+3871)=2790kips/in

T=2•3.14• $\sqrt{M/K}$ =6.28• $\sqrt{13.6/2790}$ =0.438s

damping constant $C_2=\xi_2$•4•3.14•M / T=128 kip.s/in

The dynamic calculation of this non-classically damped linear system can also be performed by NONLIN. Inputting a same earthquake as above, we got the frame elastic force peak value=4756kips.

The isolation effectiveness=(7328-4756)/7328=36%.

The isolation effectiveness depends on the isolator damping ratio ξ_2. If ξ_2 is changed to 5%, then the frame elastic force peak value will become 5691 kips, isolation effectiveness=(7328-5691)/7328=22%.

The isolation effectiveness also depends on the stiffness ratio K_1/K_2. If K_1 is decreased to 3871 kips/in, iz. $K_1/K_2=1$, given the same earthquake, then the un-isolated frame elastic force is increased from 7328kips to 7727 kips. The isolated frame elastic force is increased from 4756 kips to 5909kips. The isolation effectiveness is (7727-5909)/7727= 24%.

CONCLUSION

From above we tend to think that the behavior of BS cushion can be simulated by equivalent stiffness model with equivalent damping ratio. The above reasonable calculations give the fact that due to the isolation and energy dissipation of BS cushion, it has 36% isolation effectiveness to the existing trial building, which is less than earlier estimation (50%). BS cushion isolated buildings can be modeled as 2-DOF systems, which is the most simplified model. To model it as 1-DOF system (iz. Structure above BS cushion was regarded as rigid body) is not correct. Based on the modeling and calculation approach presented in this paper, it is possible to reach 50% of isolation effectiveness for a future design by improving the design philosophy and BS cushion material. From the view of engineering, 50% of isolation effectiveness is moderate but can be regarded significant. (For example, according to Chinese seismic design code, 50% isolation effectiveness can result in a cut at one degree of earthquake intensity to the seismic design of upper structure). That means BS cushion provides adequate possibility for seismic engineer to design a safer and more economic structure in earthquake prone regions.

ACKNOWLEDGEMENT

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