ELASTOPLASTIC SPRING ELEMENTS FOR DIMINUTION OF SEISMIC FORCES AND ABSORBTION OF KINETIC ENERGIES RESPECTIVELY /SEISMIC ISOLATION/ +

B. Csák /I/
D.W.Haase /II/
J.Peredy /I/

SUMMARY

The paper is dealing with a version of seismic isolation the main point of which is an elasto-plastic spring system built in between the foundation and the upper structure of the building. From the application the following advantages are to be expected:

- The spring system can be followed well by calculations both in the elastic and plastic regions; consequently, the design can be made by pre-determined building movements.

- The energy absorbtion process can be assured outside the structural system; consequently, on a building protected by a spring system, cracks do not occur.

- The costs of the protection are by far less than in the case of other protection methods, used till now, because the expenses of subsequent strengthenings and repairings have not to be taken into account.

1. INTRODUCTION

The spring system, as a version of seismic isolation, has been elaborated by considering the two following important basic principles:

a/ assuring the energy absorbtion processes inside the system;

b/ the same, but outside the system.

Ad a/ Assurance of energy absorbtion inside the system is possible only by big plastic deformations of the structural elements, according to the following two cases:

- Development of spontaneous failure mechanisms in the structural system. Its great disadvantage is that such essential structural elements are failing /first of all because of loss of stability/, the falling out of which causes progressive collapse. Consequently, the energy absorbtion capacity of the system is not exhausted but is broken off.

/I/ Associate professor of the Technical University of Budapest

/II/ General sales manager of MTS Systems GmbH in West-Berlin

\+ The system is a service patent of the Technical University of Budapest.

- By construction of sidesway mechanisms based on the principle of limit design it is attainable, that plastic hinges should be formed at those points of the system where alternate or plastic deformations do not start loss of stability.

The process of energy absorbtion is concentrated in the localized cross-sections of the plastic hinges; experiences till now prove that this is well resoluble.

This method of protection raises two economic questions:

- The costs of protection are relatively high; they can reach the 4-6 % of the total building costs.
- Because of the plastic deformations heavy structural and other damages occur. The costs of the subsequent strengthenings and repairings are very high; they can reach the 40-60 % of the original building costs.

Ad b/ Because of the above-mentioned reasons, the interest in methods based on the principles of seismic isolation is intensifying;these methods try to assure energy absorbtion outside the structural system.

In the following part of the paper a solution belonging to these methods will be outlined.

2. SHORT DESCRIPTION OF THE SOLUTION

2.1 General description, application fields

The spring system can be built in - according to Figs.1.-2. - between the foundation and the upper structure of the building, based on the following principles:

- The horizontal resistance R /x;t/ of the spring system is determined by the consideration that the system should be under the maximum wind load effect in elastic limit state /Fig.3./. The upper part of the building is designed to resist the internal forces caused by wind load and other effects. In the case of high buildings it is possible that the spring system should work also as an element in tension to hamper overturning.
- In the case of earthquake the spring system, plastified according to figure 4, is suitable to transmit such accelerations only, the seismic forces of which are scarcely greater than the maximum wind loads. According to Fig.4., the plastic movements of the building can be controlled in such a way, that after reaching a limit value new spring elements enter, according to the principles of "progressive springing". This requirement may be very important in the case of buildings susceptible to movements, e.g. nuclear plants, etc.
- The spring system can be built in into the building cross-section in such a way that - according to Fig.5. - the eccentricities e_x , e_y between centre of rigidity and centre of mass should

be equal to zero or should be an upper limit of a desired value. In this way the torsionswings can be eliminated.

- The spring system can be calculated very accurately both in elastic and plastic regions. This enables that on the protected building neither the internal forces nor the deformations should exceed predetermined limit values. Figs. 6-9. represent other application methods and fields.

2.2 Short description of the spring system

Fig. 10. represents one element of the spring system; it consists of two principal parts:

- The vertical loads are supported by sandwich-system rubber springs, which have also considerable horizontal rigidities.

- The elasto-plastic horizontal rigidity is assured by short steel columns, the two ends of which are fixed in steel tubes fastened in concrete. These columns do not support vertical loads, they are submitted therefore to bending moments and shear forces only. On their ends plastic hinges are formed in the plane of the fixing. Their plastic deformation - and so their energy absorbtion capacity too - is very big; this is proved also by tests.

3. CALCULATION METHODS AND RESULTS

3.1 Calculation model

Simplifying assumptions according Fig. 11.are introduced; in the case of practical problems they are fulfilled by a good approach.

- The spring system is visco-elastoplastic.

- In elastic region the system is linear;
  $R/x;t/ = k.x/t/$. See Fig.11/a.

- In plastic region the rigidity of the system is taken into consideration according to a rigid-plastic model. See Fig.11/b.

- Both the foundation and the upper structure is considered as a perfectly rigid body, which is linked by the spring system. Consequently, the swinging system is treated as a one degree of freedom system.

- The relative movements acting on the system - the seismogram - is substituted by approaching impulse series.

3.2 Analysis in elastic state

Demand on assurance of fully elastic state can be required. Calculation of the transient response of linear systems is well known, some principle steps of forming the response spectrum is therefore referred to only in brief.

Taking into account the total displacement of the mass m;

$$x_{REL} = x/t/ - x_o/t/; \quad \text{Fig. 12.}$$

In this case the notion of the system:

$$m\,\ddot{x}/t/ + d\,\dot{}\,/t/ + k\,x/t/ = m\,\ddot{x}_o/t/ \qquad /3.1/$$

or: if substituting $m\,\ddot{x}_o/t/$ with $F_o/t/$ and the instant $t = 0$ the system is at rest:

$$x/0/ = 0\ ;\ \dot{x}/0/ = 0$$

the solution of eq/3.1/ is furnished by the DUHAMEL integral:

$$x/t/ = \frac{1}{m\omega_o\sqrt{1-\gamma^2}}\int_0^t F_o/t_1/.ee^{-\gamma\omega_o(t-t_1)}\sin\left[\omega_o\sqrt{1-\gamma^2}\,/t-t_1/\right]dt_1 \qquad /3.2/$$

where:

$\omega_o = \sqrt{\frac{k}{m}}$ the natural circ.frequency of the system when $d = 0$

$\gamma = \frac{b}{2\sqrt{k.m}}$ the damping factor

Substituting in eq/3.2/ $F_o/t/$ with $m\,\ddot{x}_o/t/$ and $\omega_o = \frac{2\pi}{T_o}$; T_o is the periodtime of ground frequency, we obtain the solution of /3.2/ in the form:

$$x/t/ = \frac{T_o}{2\pi\sqrt{1-\gamma^2}}\int_0^t \ddot{x}_o/t_1/e^{-\frac{2\pi}{T_o}\gamma(t-t_1)}\sin\left[\frac{2\pi}{T_o}\sqrt{1-\gamma^2}\,/t-t_1\right]/dt_1 \qquad /3.3/$$

The max. values:

$$Sd = x_{max} = \frac{T_o}{2\pi\sqrt{1-\gamma^2}}S_v;\ \text{or if } \sqrt{1-\gamma^2}\sim 1{,}00;\ S_d = x_{max} = \frac{T_o}{2\pi}.S_v$$

we can consider: $\dot{x}_{max} = S_v$; the max.acceleration; $S_a = /\ddot{x}-\ddot{x}_{o\,max}/ = \frac{2\pi}{T_o}.S_v$

3.3 Analysis in plastic limit state

Similarly to the elastic state, determination of the transient response is the task are here. In the plastic state, however, principles and methods of the linear theory are no more valid.

Nevertheless, the simplifications outlined in paragraph 3.1 are considered as effective.

- According to Fig. 13., the acceleration function, accurring on the plastic system,

  $$a/t/ = \left|\frac{Rp/t/}{m}\right|$$

  is known. If, in a given point of time, during a short period dt, an acceleration a/t/ is acting on the system, under the effect of this, in the point of time t_a , a displacement

  $$dx/t/ = a/t/\ dt\ /t_a-t/ \qquad /3.4/$$

  arises. If the effect of the acceleration occurring in every point of time t is considered:

  $$x/t_a/ = \int_0^{t_a} dx/t/dt = \int_0^{t_a} a/t/\ dt/t_a-t/ \qquad /3.5/$$

i.e.: the plastic deformation /displacement/ of a mass m is equal to the statical moment of the acceleration diagram on the axis corresponding to the point of time t_a.

- A characteristic, easily calculable supposed case of the relative movement is the pure sinusoid induction /Fig.13./. The plastic displacement at the end of the n-th sinus wave is:

$$x/T_{a;n}/ = n. \frac{R_p/t/}{m} . / \frac{T}{2} /^2 \qquad /3.6/$$

  Greater displacements than this may arise mathematically only in the case when the soil returns in its state of rest with a greater velocity as it moved. The seismograms, however, do not show such a tendency; the displacement, occured under the effect of the sinusoid movement is considered therefore as the upper limit of the displacements.

- An other, easily treatable supposed movement is the purely cosinusoid soil movement, under the effect of which the displacement is, at the end of the n-th cosinus wave, equal to zero:

$$x/t_{a;n}/ = n. \frac{R_b/t/}{m} .0 = 0 \qquad /3.7/$$

- The seismograms on the real earthquakes are at most the combinations of the previous two cases, under the effect of which the displacement falls between the previous two limit values.

- Numerical analysis has been made for the case of the general displacement function by a program worked out for the personal computer SINCLAIR 2xSPECTRUM.

  Basic element of these calculations is the modelling of the earth movements which were taken according to Fig.14. Here t_1 , t_2, ... are probability variables in the time interval of 0.06 - 0.12 sec, independent from each other and from the amplitudes x_{01}, x_{02}, ...

  The amplitudes x_{01} , x_{02} , ... come from formula

$$x_{oi} = /x_{oi-1} + x_{ori}/. \frac{1}{2} ; \quad x_o/0/ = 0$$

where the values x_{ori} are equally distributed probability variables in the interval 0 - 2.0 cm, independent from each other and from the t_i values.

The rest periods $/t_3, t_5/$, during an earthquake of a period of 50 sec, were taken as random events with a probability P = 0.3; this is a random induction movement. The results of the numerical example shown in Fig.15. are represented in Table I.

4. TESTS, TEST RESULTS

Results of tests can give answer to two principal questions:

- Is the energy absorbtion capacity of the spring system sufficient? The results of tests carried out in the laboratory of MTS Systems GmBH, West Berlin, have given a reassuring answer /Figs.16.-17./.

- Is the spring system suitable for the diminution of the movement characteristics /acceleration, velocity/, by prescribed values, in the upper part of the building? How are the real displacements in elastic and plastic state?

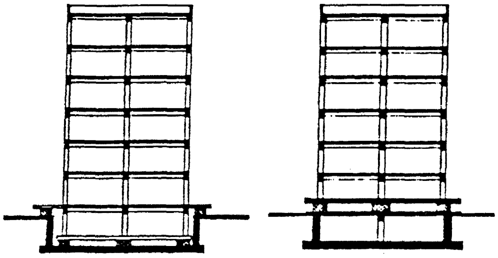
These questions will be answered by the shake table tests, at present in preparation. We shall give account of the results on the conference.

5. ACKNOWLEDGEMENTS

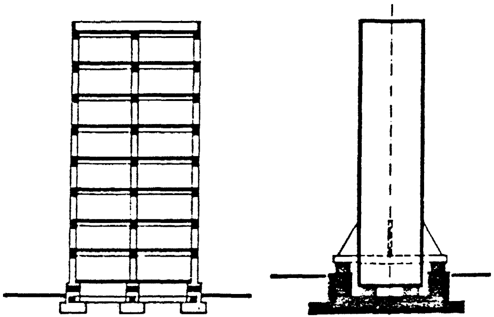
We express our acknowledgements to the Hungarian Ministry of Construction and Urban Development and to UNIDO, for the support furnished within the UNDP/UNIDO Project RER/79/015, BUILDING CONSTRUCTION UNDER SEISMIC CONDITIONS IN THE BALKAN REGION, and to the management of MTS Systems GmBH, for the aid given to the carrying out of the tests.

REFERENCES

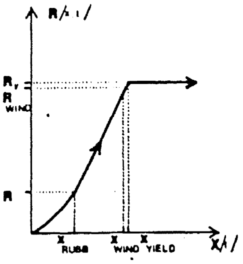
1 J.Petrovski-V.Simovski: Dynamic response of base-isolated building. Proceedings of the 7th European Conf.on E.E.Vol.4.
2 C.J.Derham;J.M.Eidinger;J.M.Kelly;A.G.Thomas:Erdbebensicherung mit Naturgummi-Fundamentbaulagern-Versuchergebnisse. Naturkautschuk Technologie.Jahrgang 8.Teil 3.1977.
3 C.J.Derham: Rubber bearings for base isolation of structures. Asian Reg.Conf.on Tall Building and Urban Habitat. Aug.17-20. 1982.Kuala Lumpur.
4 J.P.Wolf;P.Obernhuber;B.Weber: Response of a nuclear power plant on aseismic bearings to horizontally propagating waves. Earthquake eng. and struct.dynamic Vol.11.1983.



DAMPING OF RIGID BUILDINGS
FIG.1.

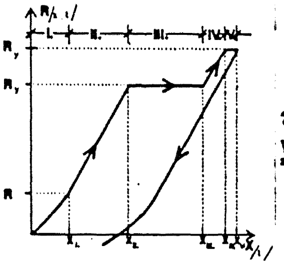


SOLITER FOUNDATIONS DAMPING OF TOWER BUILDINGS
FIG.2.



WIND EFFECT.
DISPLACEMENT —
RESISTANCE DIAGRAM

FIG.3.



SEISMIC EFFECT.
DISPLACEMENT —
RESISTANCE DIAGRAM
PROGRESSIV SPRINGING

FIG.4.

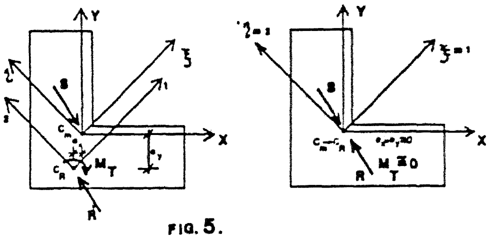
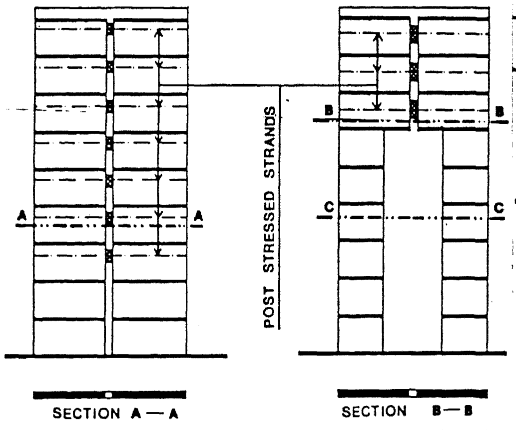


FIG. 5.



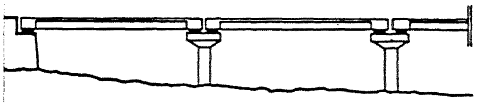
SECTION A — A

CONNECTIONS OF SHEAR WALLS

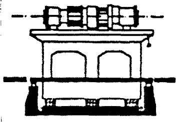
SECTION B — B

SECTION C — C

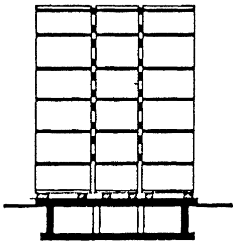
FIG. 6.



BRIDGE STRUCTURES
FIG



MACHINE AND TURBINE FOUNDATION
FIG.9.



SHEAR CONNECTIONS OF LARGE PANELS
FIG.7.

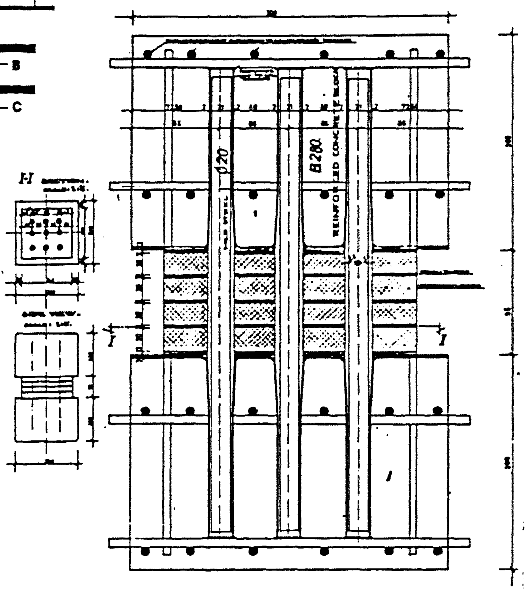
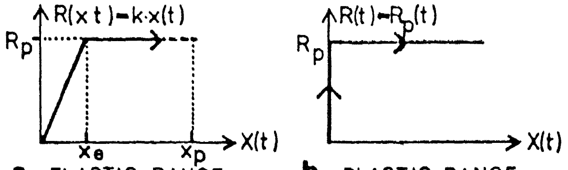


FIG.10. ELASTOPLASTIC SPRING ELEMENT. SCALE 1:1 . VERTICAL SECTION.



a; ELASTIC RANGE **b**; PLASTIC RANGE

FIG. 11.

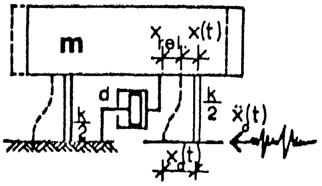


FIG. 12.

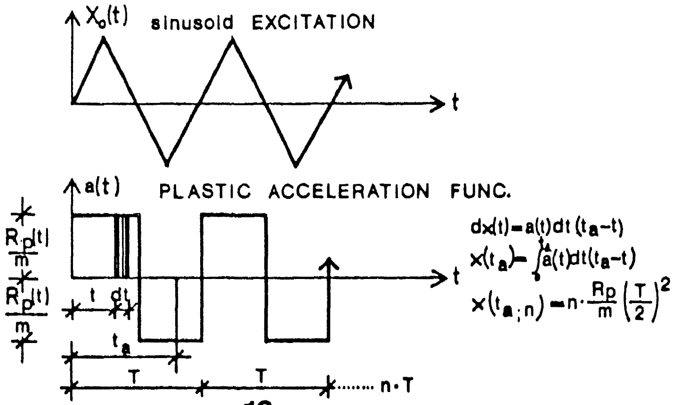
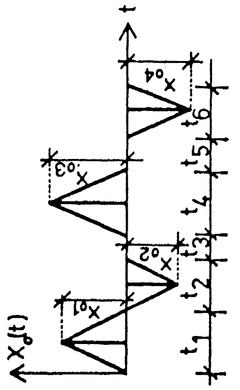


FIG. 13.



RANDOM EXCITATION

FIG. 14.

NUMERICAL EXEMPLAR FIG. 15.

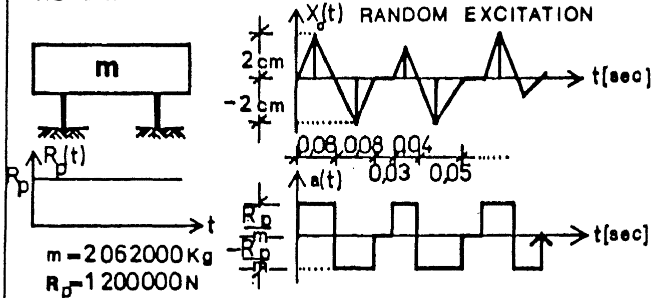


TABLE I.

NO	THE WHOLE TIME (sec)	THE MAX PLAST.D.(cm)
1.	51,10	5,6841
2.	51,04	4,1066
3.	51,10	3,6512
4.	51,03	3,0247
5.	51,10	7,9501
6.	51,06	6,3404
7.	51,03	5,2343
8.	51,05	3,3413
9.	51,06	4,9608
10.	48,60	4,1984
11.	51,04	5,1383

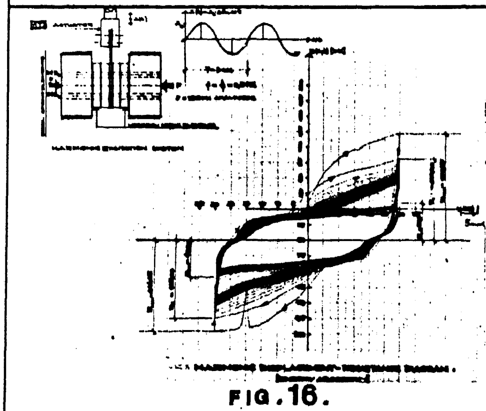


FIG. 16.

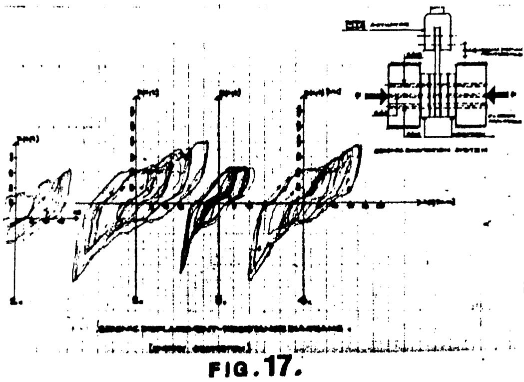


FIG. 17.