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New approach to seismic base isolation

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ABSTRACT

A flexible mounting and an energy dissipation mechanism are considered to be the two basic elements in most of practical base isolation systems. At the same time an effect of energy dissipation in the frequency spectrum area that is rather distant from resonant frequencies, what is just typical for flexible mounting, is actually negligible. Besides, a reduction of relative displacement of a superstructure with respect to its foundation, which is proclaimed as a goal of said dissipation is none other than a result of transmission of earthquake movement into the superstructure and therefore should be avoided.

A new concept embodied in the Antifriction and Multi-Step Base Isolation (AF&MS BI) is an alternative approach [3, 4, 5]. The global strategy of the AF&MS BI may be set out as follows: there is no sense both in trying to resist violent tremors and to damp them, it is much easier to escape.

The main advantage of the AF&MS BI lies in its double level protection. A mechanism of the first level lessens an intensity of the earthquake input itself. The second level reduces dynamic responses of the structure.

AF&MS BI REALIZATION

To minimize transmission of destructive earthquake ground motion into a structure, to prevent permanent horizontal post-earthquake offsets, to keep the system's ability to withstand wind pressure as well as minor earthquakes without being decoupled from its foundation, the AF&MS BI consists (Fig.1) of a ball transfer unit (1) supporting a superstructure (2) and resting on a depression (3) of a pedestal plate (4). The depression is shaped in compliance with the configuration of the contacting surface of the ball and is centered at the lowest point of the pedestal plate (4) having a concave upper surface (5) and resting on a foundation (6). The depth of the depression at given radius of the ball is governed by weight of the superstructure and by design wind load. The force of gravity will keep the superstructure in a steady position on the pedestal plate both at any wind at a slight earthquakes. When

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magnitude of the earth movement exceeds a certain threshold, the ball gets out of the depression, any transfer of horisontal movement to the superstructure considerably decreases.

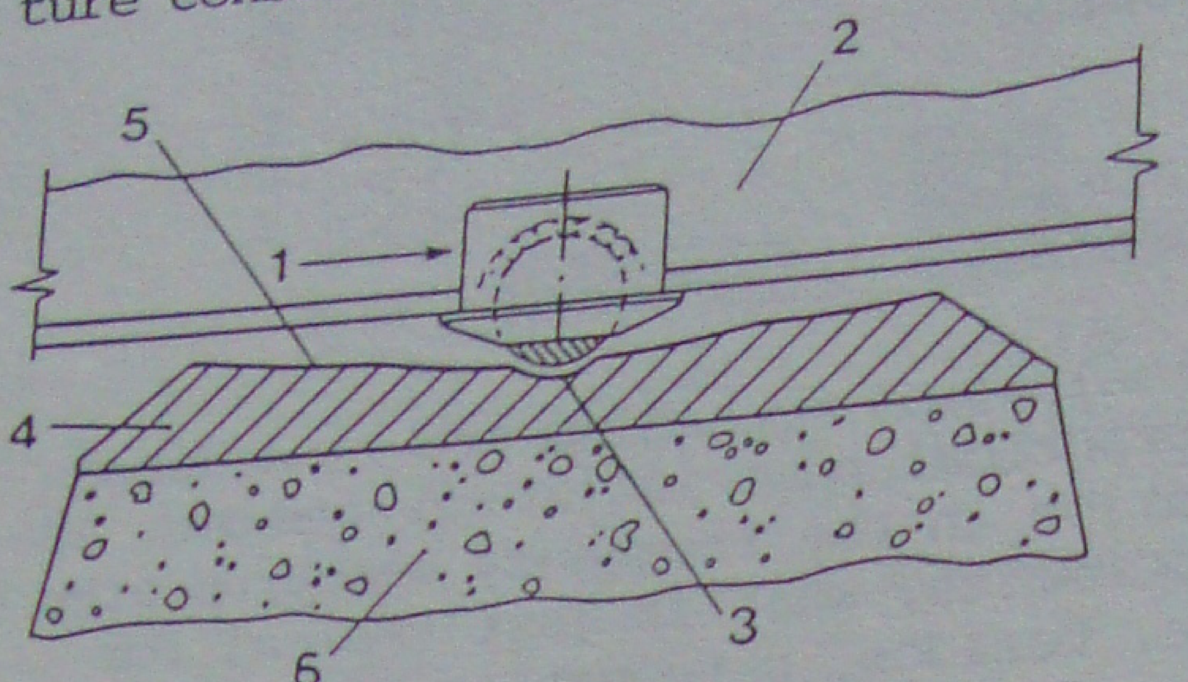

Figure 1. AF&MS BI unit

To confine the base shear as well as the travel of the superstructure by an acceptable leval, the upper surface of the pedestal plate is shaped as a combination of concentric spherical surfaces with successively increasing radii of curvature which are continuously transforming into each other. Maximum vertical grade of every component surface is the same and approximately equals to the ratio of the design wind load to the weight of the superstructure (Fig.2). This design of upper surface provides a multi-step base isolation by means of successive tuning-out the forcibly vibrating system, thus protecting it from resonant amplification. The diameter of the cavity in the pedestal plate is not to be less than a double maximum amplitude

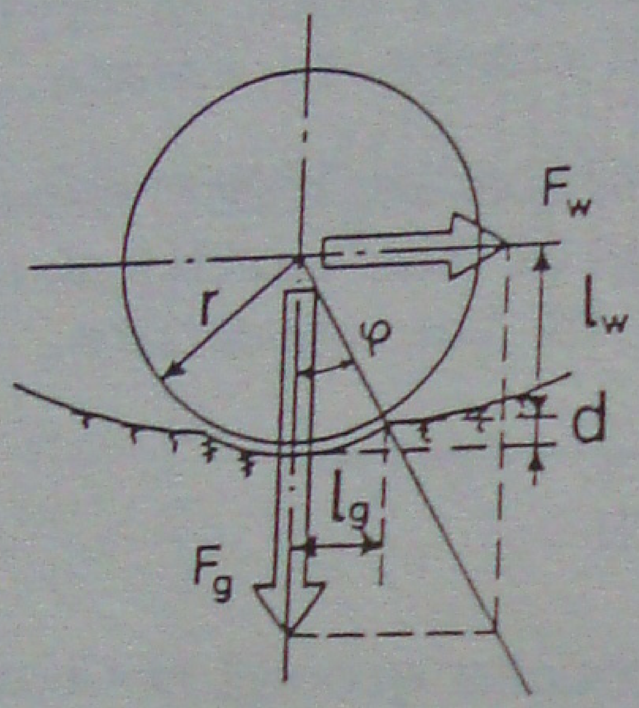

Figure 2. Diagram of forces for ball in central depression

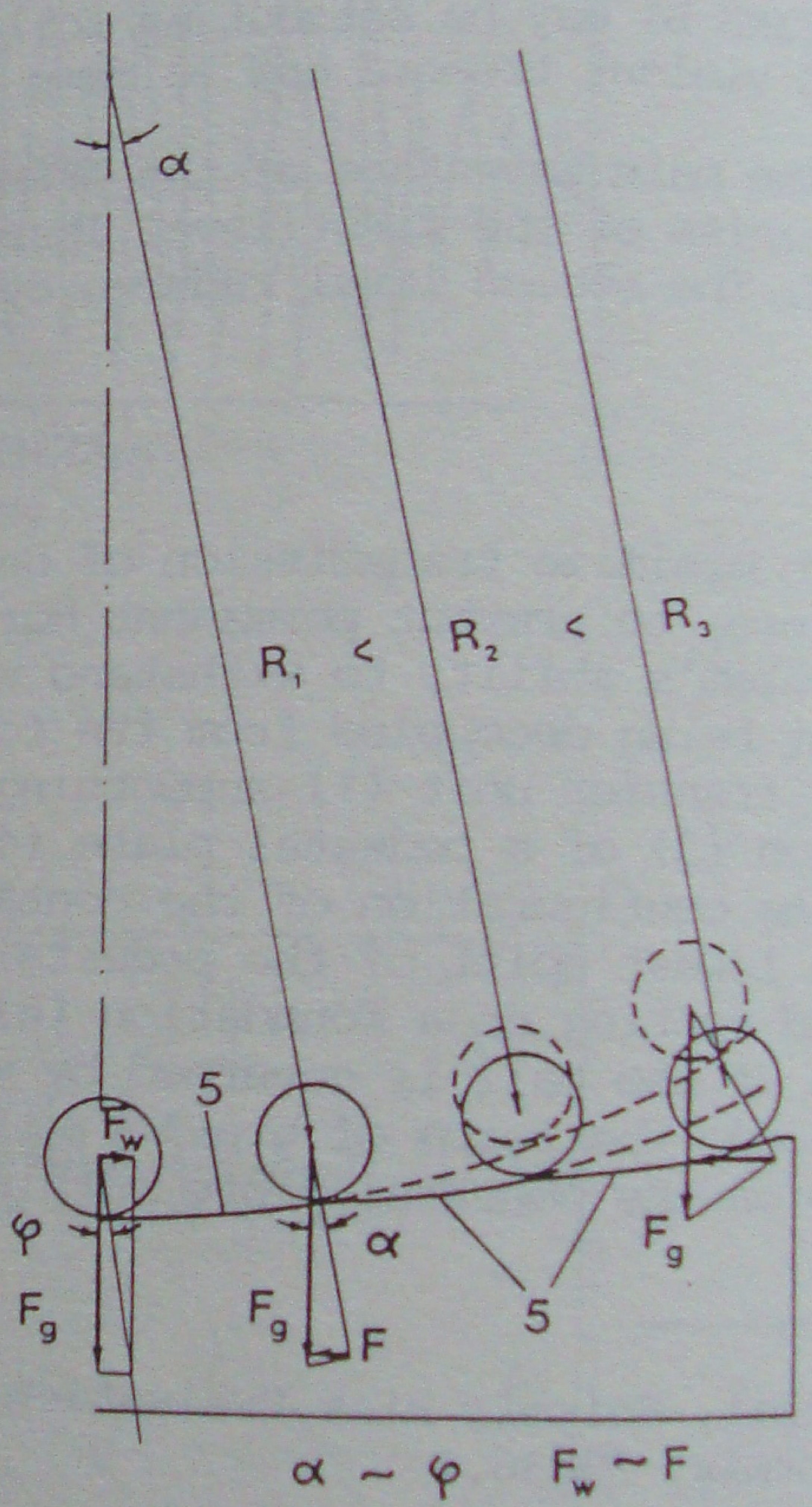

Figure 3. Fragment of multi-curved surface with balls in critical positions

of earth displacement during a strong earthquake. The radius of vertical curvature of the central sphere of the upper surface of the pedestal plate is designed as big as to provide a proper tuning-out natural frequencies of the base-isolated from the fix base structure.

One of the most critical characteristics of any seismic isolator is its load-deflection curve. Subject to a particular material and design, those curves may differ in details but in the main thing they are very much the same: with an increase of deflection the corresponding horizontal reaction in the system steadily builds up (Figs.3,4). The case is entirely different in the event of the AF&MS BI: with this concept now it becomes possible to create isolators of any set properties simply by changing their pedestal plates' configuration. Thus, the AF&MS BI is not only the next but the simplest and the most powerful seismic-isolation technology.

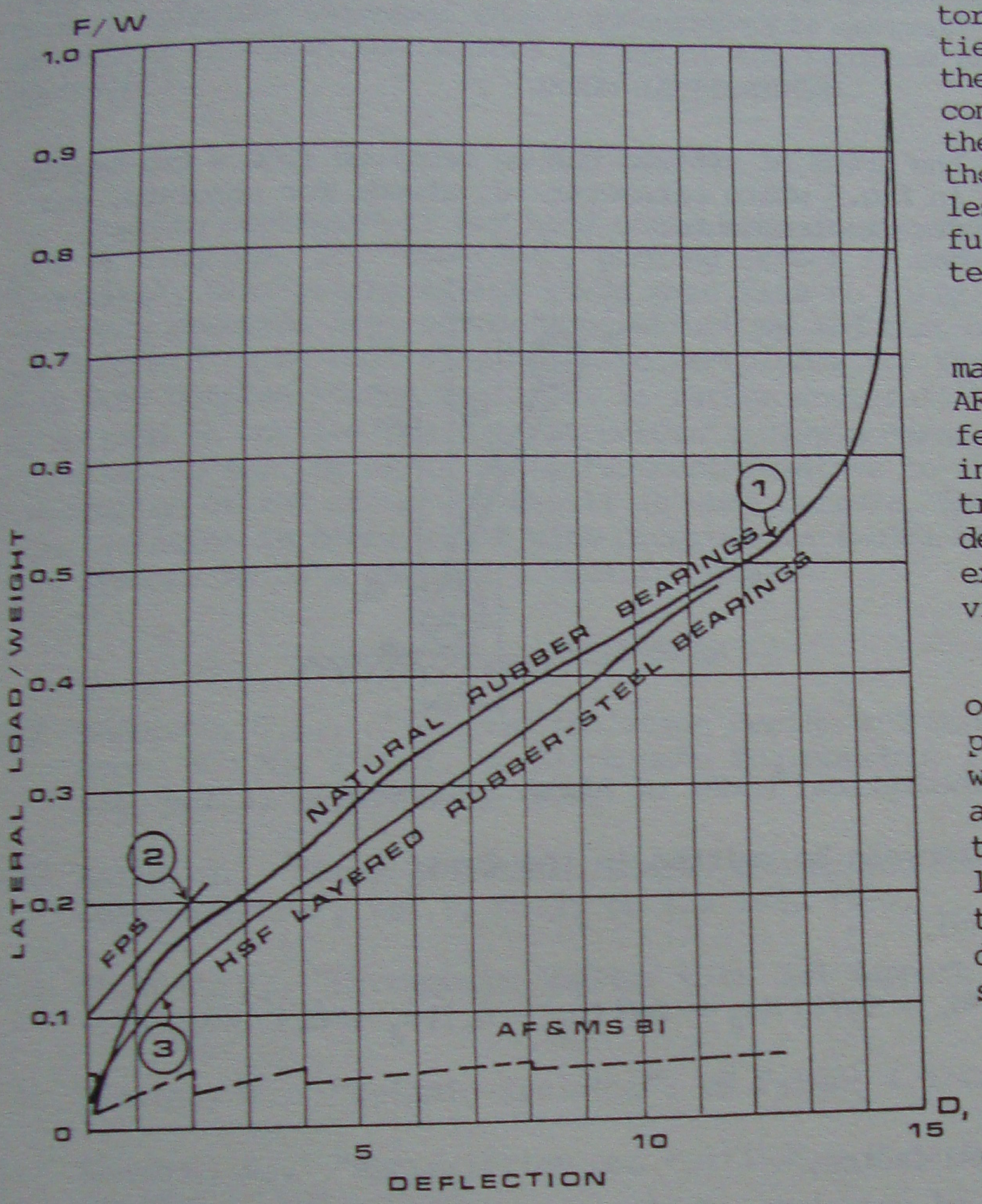

Figure 4. Load-deflection curves of different types of base isolators, investigated by:

1 - T. Anderson [1]; 2 - V. Zayas et al [7];
3 - F. Tajirian et al [6]

By the way, the main component of the AF&MS BI, a Ball Transfer Unit is widely used in stationary and mobile transport systems intended for heavy duty and extreme condition environments.

Another advantage of the AF&MS BI in comparison, for example, with rubber bearings is an absence of alternating eccentrically applied vertical base reactions which can excite damaging flextural stress waves.

The AF&MS BI can be easily applied both to new constructed and to retrofitting existing structures. It is incomparable for one-two story buildings which cannot be effectively equipped with any other type of base isolators.

CONDENSED PHILOSOPHY OF SEISMIC ISOLATION

Leave buildings alone, do not tie them to the ground and decrease to the utmost extent any existing lateral ties, or briefly: let the earth move its way.

Remember: it is not the building, it is the earth which is vibrating when the building is supported on an adequate isolation system. Any attempt to reduce a relative displacement of the superstructure with respect to the foundation inevitably results in an additional transmission of earthquake energy into the building.

MATHEMATICAL MODEL

Basic features of the AF&MS BI systems can be received from a two-degree-of-freedom model shown in Fig.5 where parameter u stands for absolute, and parameter v for relative displacements.

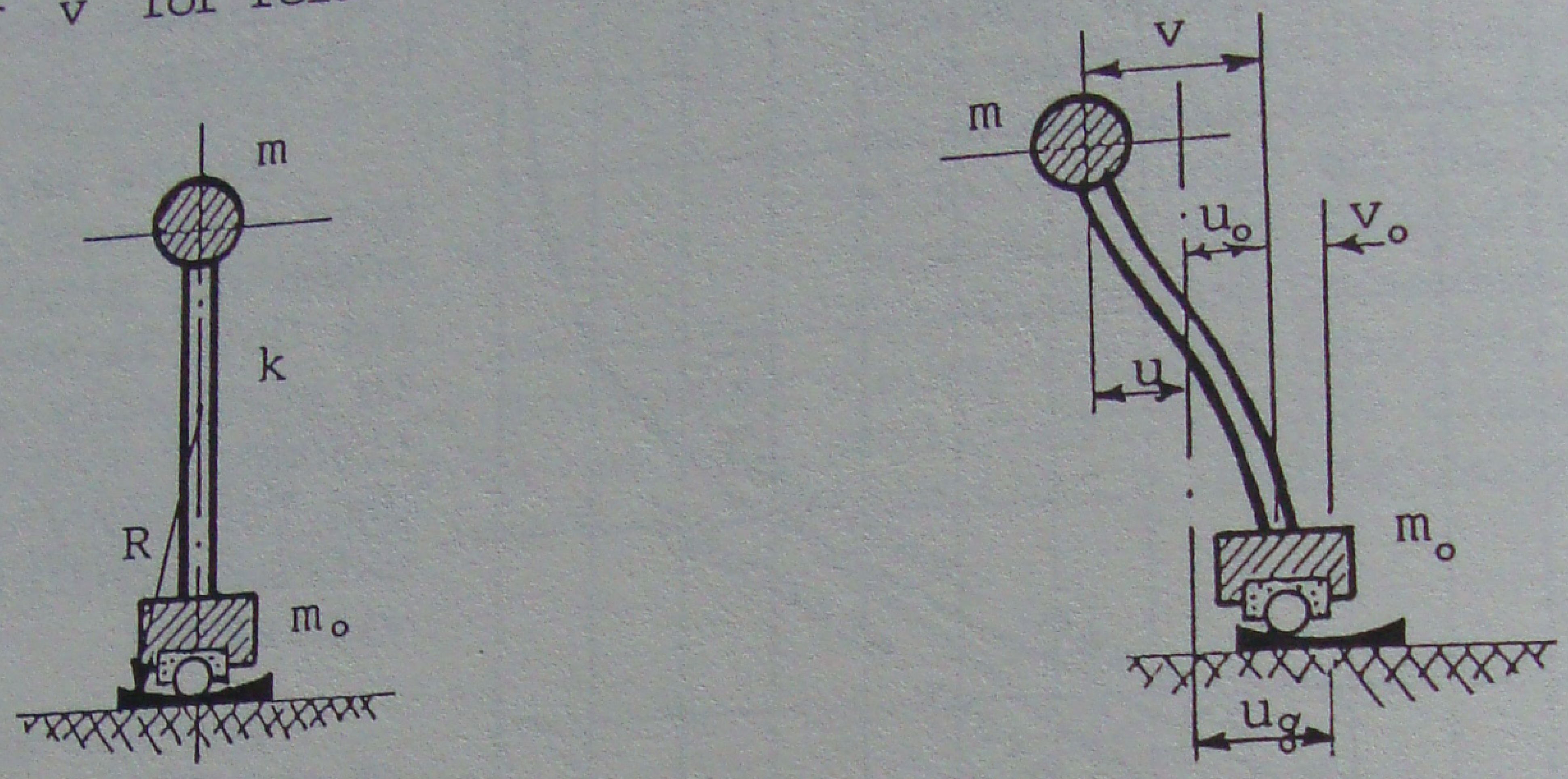

Figure 5. Theoretical model of AF&MS BI system

The equation of motion can be written in the form:

$$\begin{cases} m\ddot{v} + r\dot{v} + kv = -m\ddot{u}_o \\ M\ddot{u}_o + m\ddot{v} + (g/R)Mu_o = (g/R)Mu_g + fgM(\dot{u}_g - \dot{u}_o)|\dot{u}_g - \dot{u}_o|^{-1} \end{cases}$$

where $M = m + m_o$

f is the friction factor,

R the radius of curvature of the pedestal plate in the point of the ball's instant contact,

$v = u - u_o$

From the first equation it is easy to see that deformations of a superstructure are fully governed by an external force which is equal to the inertia force of the superstructure as a rigid body rocking on isolators.

The second equation shows that an external force acting on a base-isolated structure consists of two components. One of them is proportional to the ground displacement and inversely proportional to the radius of curvature R. another is proportional to the friction factor f and is acting opposit to the sense of relative velocity $\dot{v}_o = \dot{u}_o - \dot{u}_g$. As long as $(\dot{u}_o)_{amp} < (\dot{u}_g)_{amp}$

the so called "damping force" is more exciting than damping. That is a reason for the "antifriction approach". If $(\dot{u}_o)_{amp}$ achieves the value of $(\dot{u}_g)_{amp}$, the further rate of excitation is mostly controlled by the "magic" R: any time the relative displacement v_o riches some predetermined value, the radius R sharply increases thus correspondently decreasing the external force as well as changing the natural period of the isolated structure ("multi-step approach").

CONCLUSIONS

Damping mechanism of any kind under kinematic exitation is simultaneously a driving one. Its "negative", pushing effect is immediate, where as its "positive", dissipating effect needs more time to fully develop. Besides, the frequency spectrum area of the superstructure and that of the isolated system are supposed to be well separated, so usefulness for the superstructure of adding some damping to the isolators is rather doubtful. And what is more, there is no need to confine the superstructure's displacement relative to the earth, or better to say the earth's displacement relative to the superstructure. The deformation of the structure itself is what matters. Therefore, low friction base isolation in combination with progressive (multi-step) frequency separation appears to be a much more fruitful goal.

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