A DESIGN METHOD FOR HYSTERETIC DEVICE SYSTEMS

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ABSTRACT :

The Hysteretic Device System or Hyde System is a passive control concept. The controlled mechanism is an arrangement of rigid blocks coupled by elastic-plastic steel or friction devices. The aim is to dissipate the largest part of the input energy in these devices. To stabilise this mechanism during the nonlinear action of the devices, an elastic stiffening system in parallel to these devices is needed. But the stiffness may not be too high, since otherwise the energy dissipation in the devices is reduced. Such systems are particularly suitable in soft storey structures. The devices are attached in the soft storey, the motion is concentrated there and the other storeys react as a rigid body. Since soft storeys exist in a multitude of present buildings, the Hyde System is a useful concept for seismic retrofitting. To choose the necessary yielding force of the devices with respect to the allowed storey drift in the soft storey, a design curve is determined. This design curve shows the relationship between the storey drift and the yield force of the devices. For the determination of the design curve, a large number of time-consuming and error-prone nonlinear time history analyses have to be performed for various yield force levels of the devices. In this paper, a simplified calculation procedure for Hyde Systems is shown. The principal item of the procedure is an approximation for the design curve. So the large number of time history analyses is not necessary for the design anymore. The expenditure for the design of Hyde Systems reduces almost to the range of a conventionally design. By this simplified procedure, it is possible that the Hyde System concept can be used by a wider circle of engineers.

KEYWORDS: Hyde System, Hysteretic Device System, Structural Control, Passive Control

1. HYDE SYSTEM CONCEPT

A Hyde System consists of two parallel structures: A Primary Horizontal load bearing system (PHS) with Seismic Links (SL) where Hysteretic Devices (Hydes) are placed and a Secondary Horizontal load bearing system (SHS). The Primary system must be very stiff in order to concentrate horizontal displacements in its Seismic Links. The Hysteretic Devices must show almost ideal stiff-plastic behaviour by use of dry friction or yielding. Then, already small movements in the links cause plastic energy dissipation transmitting only the maximum friction or yield forces to the adjacent rigid structural blocks. These conventional structures are thus protected from overloading. A well designed Hyde System dissipates around 85% of the earthquake's input energy and thus leads to small link displacements and forces. The SHS must stabilise this mechanism with respect to the P-Δ effect during non-linear action of the PHS. It must therefore be stiff enough to perform this task; however it should not be too stiff, as this stiffness will otherwise draw energy away from the Seismic Links and thus diminish the efficiency of the Hyde System.

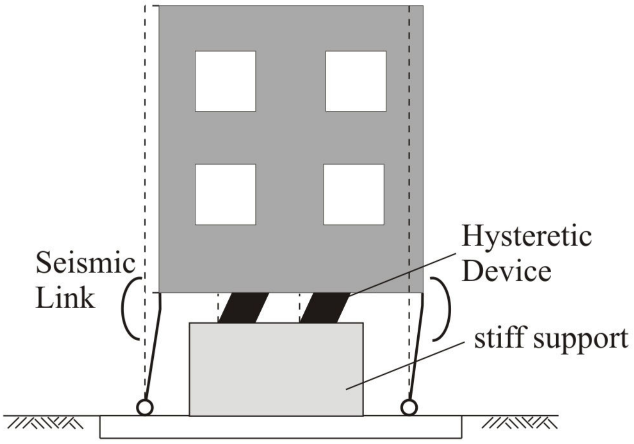

Figure 1 Mechanism of a Hyde System

2. DESIGN OF HYDE SYSTEMS

To choose the necessary yielding force (F_{Hyde}) of the Hysteretic Devices with respect to the allowed storey drift in the soft storey, a design curve is determined. This design curve shows the relationship between the storey drift and the yield force of the devices. It is limited by two elastic systems: (1) by the building without Hysteretic Devices and (2) by devices being strong enough that they do not yield (only elastic behaviour of the devices).

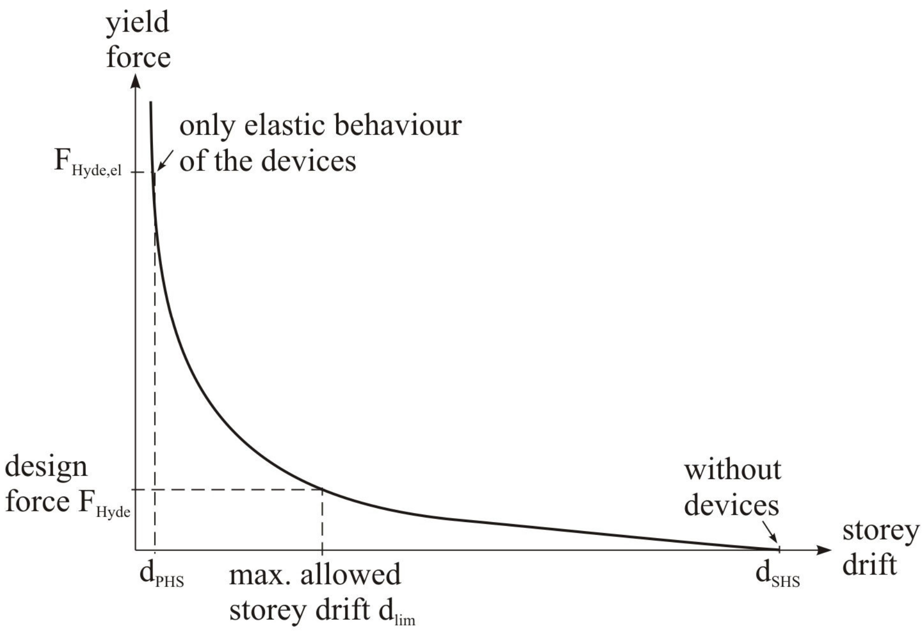

Figure 2 Design curve for a Hyde System

The design curve can be calculated by non-linear time-history analysis for different yield-levels of the devices. Typically, 4 to 5 points should be calculated covering the range between the two elastic limits of the design curve To represent the ground motion, artificial accelerograms matching the elastic code design spectrum can be used. Many codes require at least 3 of them for design. Thus, about 15 to 20 non-linear time history analyses are typically required to obtain the design curve.

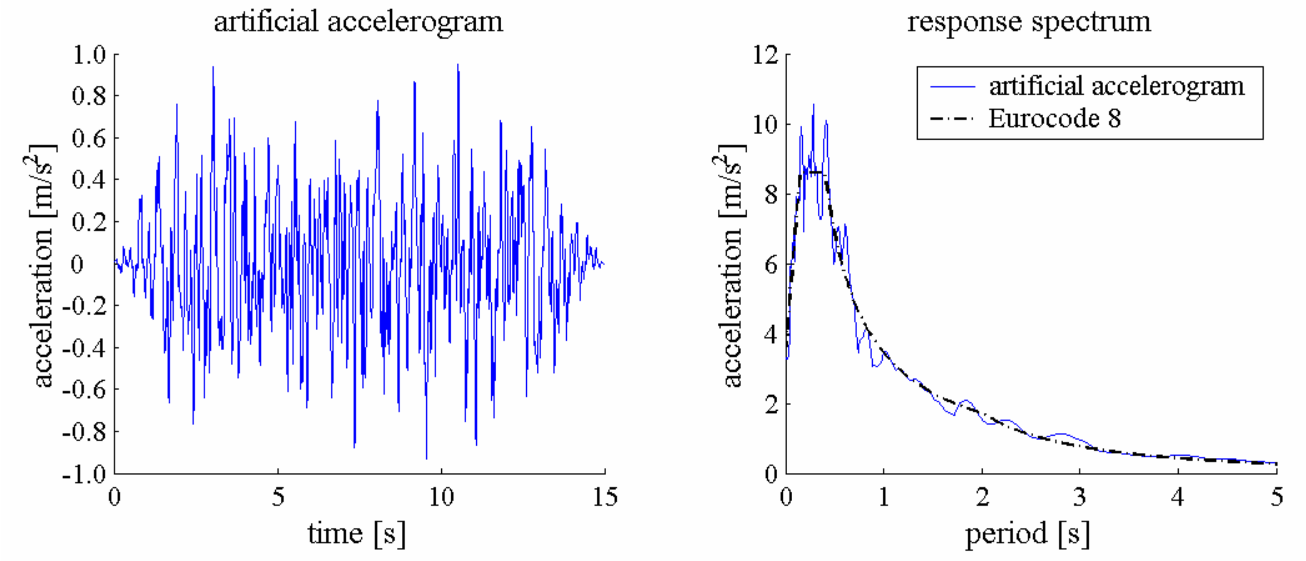

Figure 3 Artificial accelerogram matching a typical design spectrum

3. SIMPLIFIED DESIGN METHOD

To reduce the expenditure for the design of Hyde Systems, a simplified design method has been developed. By this method, only modal analysis of the building is needed. To perform the design, a linear model of the building is needed. The model without devices in the Seismic Link is used to describe the Secondary Horizontal load bearing system and the model with elastic elements for the devices is used to describe the Primary Horizontal load bearing system. By means of this model, the first eigenperiod of the Secondary and the Primary Horizontal load bearing system can be calculated. In the following, these values will be called T_{SHS} and T_{PHS}. By using modal response spectrum analysis, the deformation in the Seismic Link for the system without devices (d_{SHS}) and for the building with elastic devices (d_{PHS}) can be easily calculated. Furthermore, the force in the devices for the building with elastic devices ($F_{Hyde,el}$) is needed. For the calculation of d_{PHS}, a reduced viscous damping ratio (ξ_{PHS}) should be used. This takes into account that, by introducing the devices in the Seismic Link, the stiffness is considerably increased but not the viscous damping. Assuming mass-proportional damping, the reduced damping can be calculated without knowing the damping matrix of the model.

$$\xi_{PHS} = \frac{T_{PHS}}{T_{SHS}} \cdot \xi \qquad (3.1)$$

The simplified design method uses a scaled deformation $\bar{d}$ and a scaled Force $\bar{F}$.

$$\bar{d} = \frac{d - d_{PHS}}{d_{SHS} - d_{PHS}} \qquad (3.2)$$

$$\bar{F} = \frac{F}{F_{Hyde,el}} \qquad (3.3)$$

With this definition, the scaled deformation $\bar{d}$ is 1 for the displacement without the devices (d_{SHS}) and 0 for the displacement with elastic devices (d_{PHS}). An approximation for the scaled design curve is given as follows.

$$\bar{F} = \left(1 - \bar{d}^{a}\right)^{b} \tag{3.4}$$

The values for a and b are given in Table 3.1. These values depend on T_{SHS}, T_{PHS} and the subsoil class.

Table 3.1 Coefficients for the approximated design curve (subsoil class A according to Eurocode 8)

T_{SHS} \ T_{PHS}	0.05s	0.10s	0.15s	0.20s	0.30s	0.40s	0.50s
0.5s	a=0.11550 b=0.81176	a=0.11842 b=0.94169	a=0.28461 b=1.21242	a=0.25130 b=1.19227	a=0.29769 b=1.27318	a=0.39400 b=1.40958	a=0.55695 b=1.51362
1.0s	a=0.07085 b=0.86054	a=0.06300 b=0.97844	a=0.27530 b=1.41787	a=0.25143 b=1.33531	a=0.21332 b=1.32327	a=0.35586 b=1.46277	a=0.39396 b=1.56094
2.0s	a=0.05250 b=0.95325	a=0.07788 b=1.13271	a=0.26424 b=1.59728	a=0.21515 b=1.42264	a=0.26406 b=1.57373	a=0.31869 b=1.73450	a=0.37366 b=1.70240
3.0s	a=0.04200 b=0.93481	a=0.10406 b=1.32019	a=0.27518 b=1.64288	a=0.24668 b=1.48355	a=0.24166 b=1.60558	a=0.57017 b=1.94718	a=0.53127 b=1.90798
4.0s	a=0.05790 b=1.04675	a=0.23423 b=1.48581	a=0.29484 b=1.68561	a=0.11773 b=1.25025	a=0.30597 b=1.73704	a=0.36763 b=1.87281	a=0.46143 b=1.94854
5.0s	a=0.04200 b=0.94125	a=0.20885 b=1.51498	a=0.29496 b=1.61209	a=0.13051 b=1.31865	a=0.29931 b=1.55605	a=0.64929 b=2.08146	a=0.63898 b=2.07938

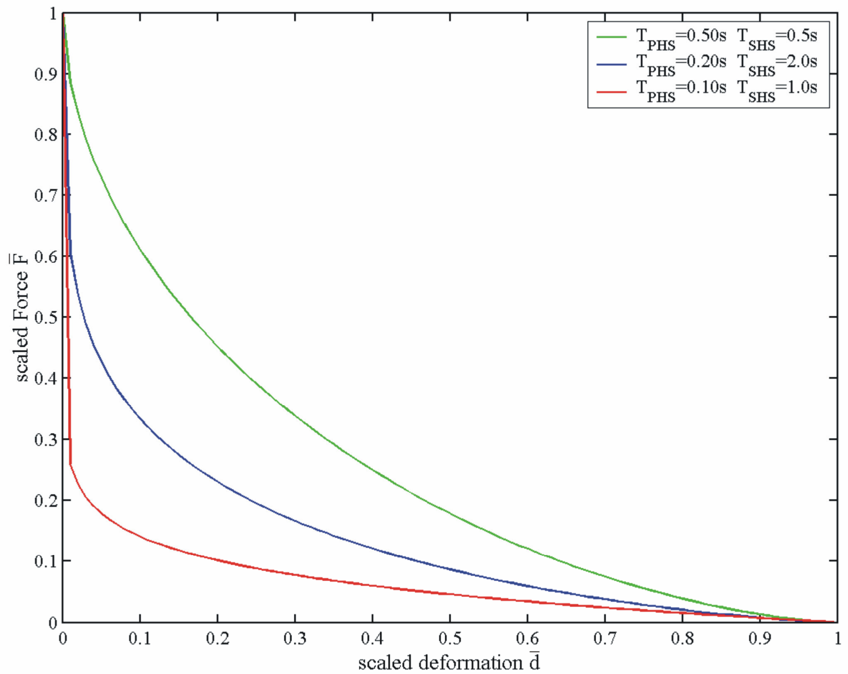

Figure 4 Scaled design curves

This simplified design method can be used, if the effective mass of the first mode of the structure is at least 90% of the total mass of the structure. This criterion is usually fulfilled for soft storey buildings.

4. DESIGN EXAMPLE FOR A 4-STOREY BUILDING

In Figure 5, a 4-storey reinforce concrete frame building is given. The Seismic Link consists of RC-walls (separated from the adjacent columns) with shear panels. The Secondary Horizontal load bearing system is the RC-frame in the ground floor.

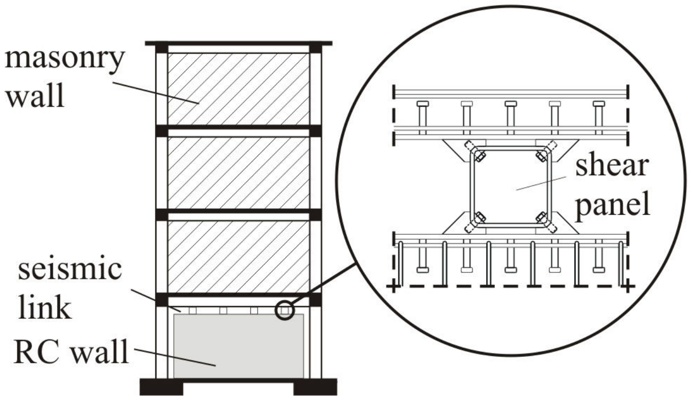

Figure 5 RC frame building with masonry infill designed as Hyde System

Except of the shear panels, all other structural elements must remain elastic during the entire earthquake. On the basis of this condition, the maximum allowed storey drift is derived from the quasi-linear limit state of the frame columns in the ground floor. A linearized moment-curvature-diagram yields a design displacement d_{lim}= 3.88 cm in this case.

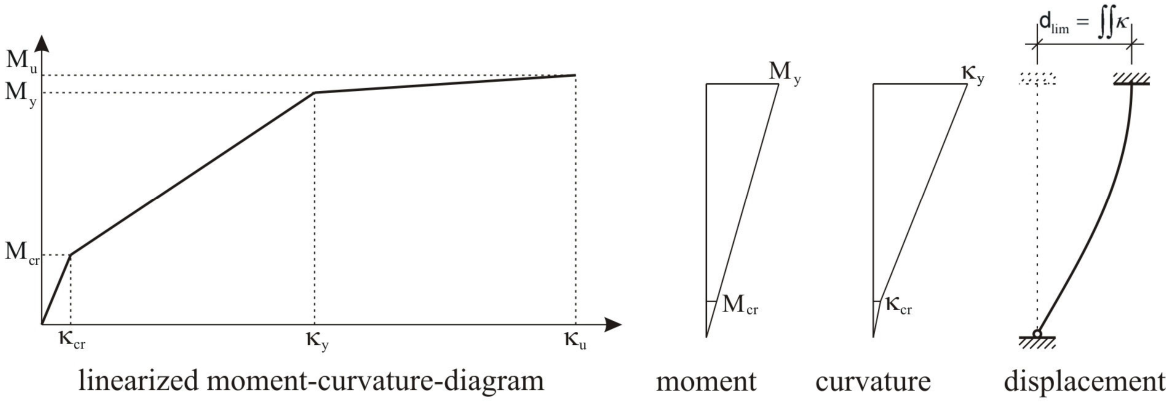

Figure 6 Design displacement defined by quasi-linear limit state of the frame columns

Figure 7 shows the first mode shape of the building without Hysteretic Devices and with elastic devices.

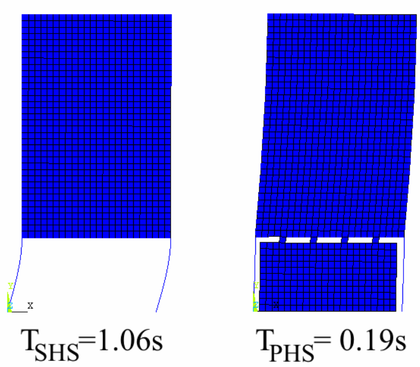

Figure 7 First mode shape of the building without and with elastic devices

The building should be designed for an earthquake with a design ground acceleration a_g of 0.35g and Subsoil Class A. A viscous damping ratio ξ of 5% is used. Therewith, the reduced viscous damping ratio can be calculated.

$$\xi_{PHS} = \frac{T_{PHS}}{T_{SHS}} \cdot \xi = \frac{0.19}{1.06} \cdot 5 = 0.90\% \tag{4.1}$$

By using modal response spectrum analysis, the two elastic limits of the design curve are d_{SHS} = 17.29 cm and d_{PHS} = 0.045 cm. The value for $F_{Hyde,el}$ is 575 kN. Therewith, the scaled design displacement can be calculated.

$$\bar{d}_{lim} = \frac{d_{lim} - d_{PHS}}{d_{SHS} - d_{PHS}} = \frac{3.88 - 0.045}{17.29 - 0.045} = 0.22 \tag{4.2}$$

The values for a and b are taken from Table 3.1 and the scaled design force as well as the design force are calculated.

$$\bar{F}_{lim} = \left(1 - \bar{d}_{lim}{}^{a}\right)^{b} = \left(1 - 0.22^{0.25143}\right)^{1.33531} = 0.2153 \tag{4.3}$$

$$F_{Hyde} = \bar{F}_{lim} \cdot F_{Hyde,el} = 0.2153 \cdot 575 = 123.8\text{kN} \tag{4.4}$$

By using equation 4.5 the Hyde forces for any storey drifts can be calculated. In figure 8, the approximated design curve and the design curve being calculated by using time history analyses are given.

$$F_{Hyde} = \left(1 - \left(\frac{d - d_{PHS}}{d_{SHS} - d_{PHS}}\right)^{a}\right)^{b} \cdot F_{Hyde,el} = \left(1 - \left(\frac{d - 0.045}{17.29 - 0.045}\right)^{0.25143}\right)^{1.33531} \cdot 575 \tag{4.5}$$

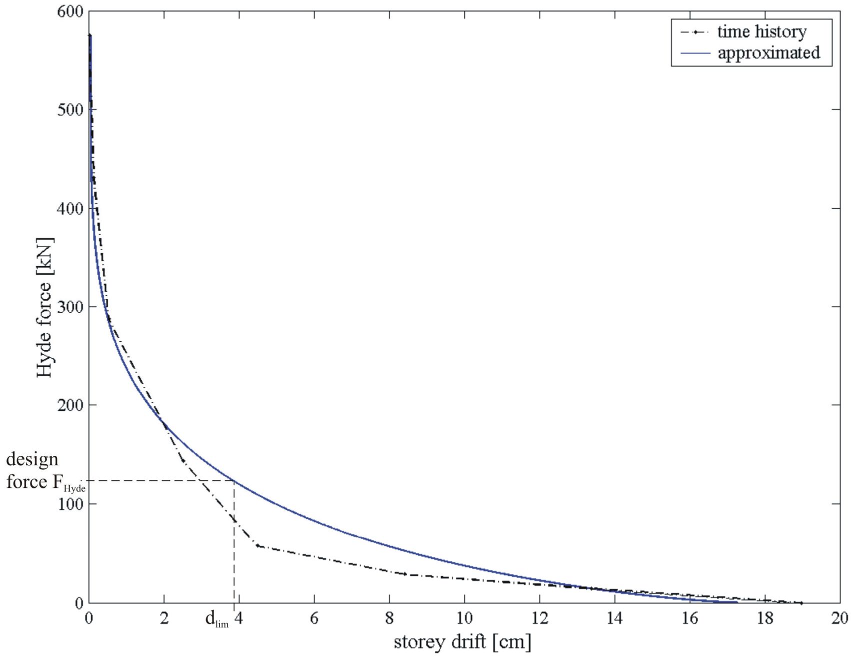

Figure 8 Design curve

To control the efficiency of the Hyde System, the energy balance for the building is calculated. Figure 9 shows that most of the energy is dissipated in the hysteretic devices.

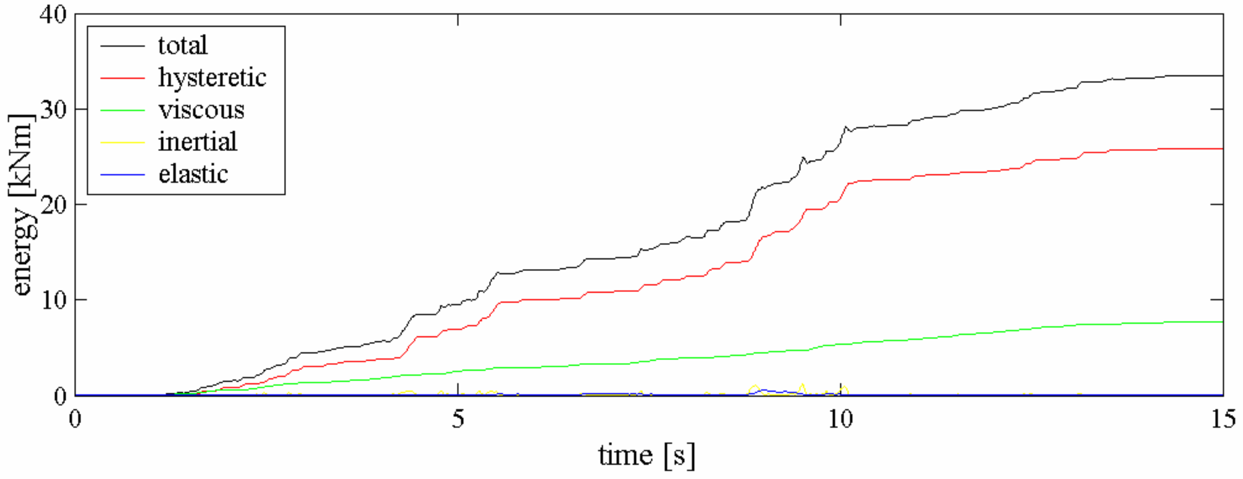

Figure 9 Energy balance under seismic loading

5. CONCLUSIONS

A simplified design method for Hysteretic Device Systems is presented. By using this method, it is not necessary to use nonlinear time history analysis. Only modal analysis of the building is needed. The calculation of the required yield force for the hysteretic devices is done using simple equations. Thus, the effort for the design of a Hyde System is considerably reduced. For the first time, this enables a quick, code based design within the time constraints of every-day structural design practice. In this paper, the simplified design method and its application demonstrated on a Hyde System design of a 4-storey building are explained.

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