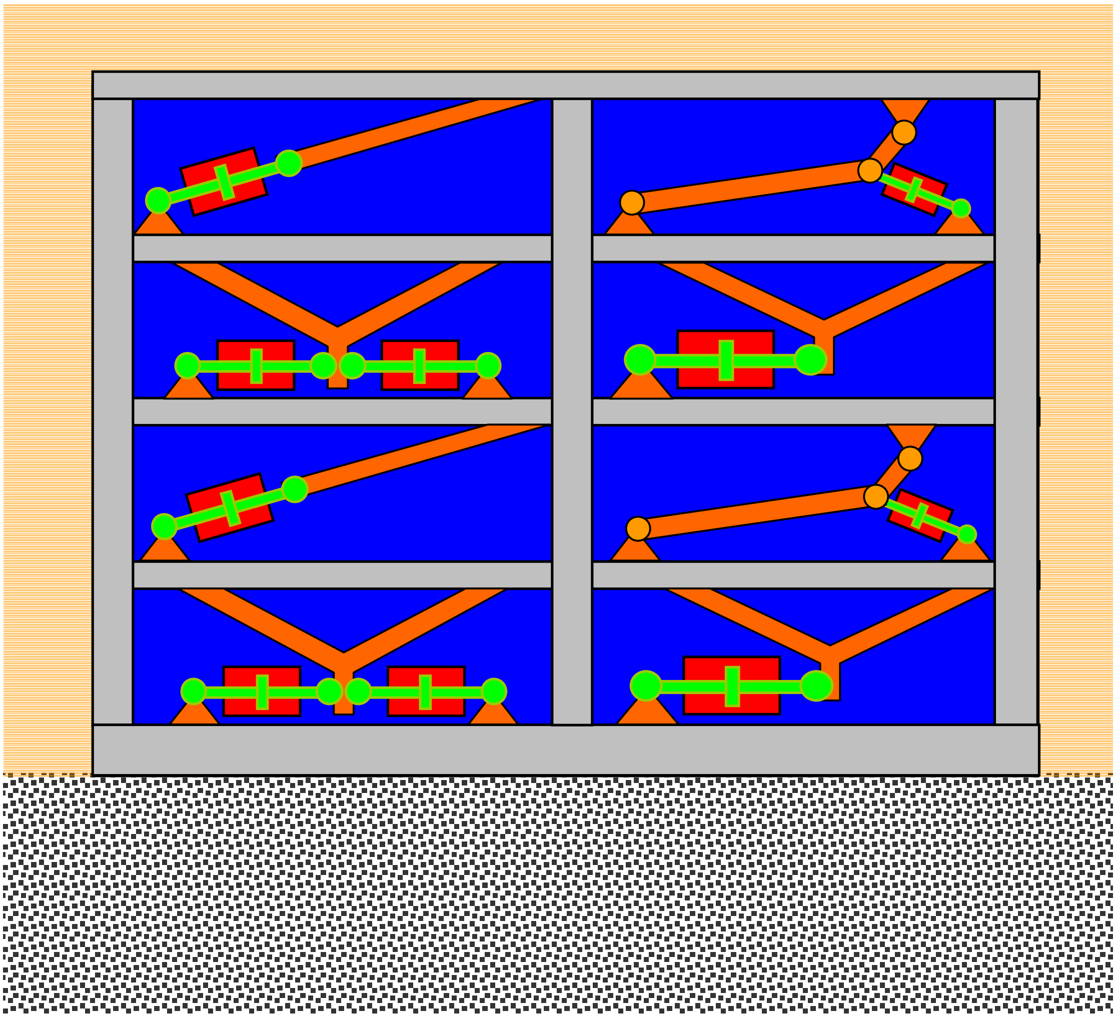
Structural protection systems

**Head Office**
Frankfurter Ring 193, 80807 München/Germany
Telephone +49 89 323 94 - 0
Telefax +49 89 323 94 - 329

**Branch Office**
Zum Holzplatz 2, 44536 Lünen/Germany
Telephone +49 231 434 01 - 0
Telefax +49 231 434 01 - 11

**Subsidiary Plant**
P.O. Box 55, 02992 Bernsdorf/Germany
Kamenzer Str. 4-6, 02994 Bernsdorf/Germany
Telephone +49 357 23 237 - 0
Telefax +49 357 23 237 - 20

# MAURER
# Seismic Building Protection

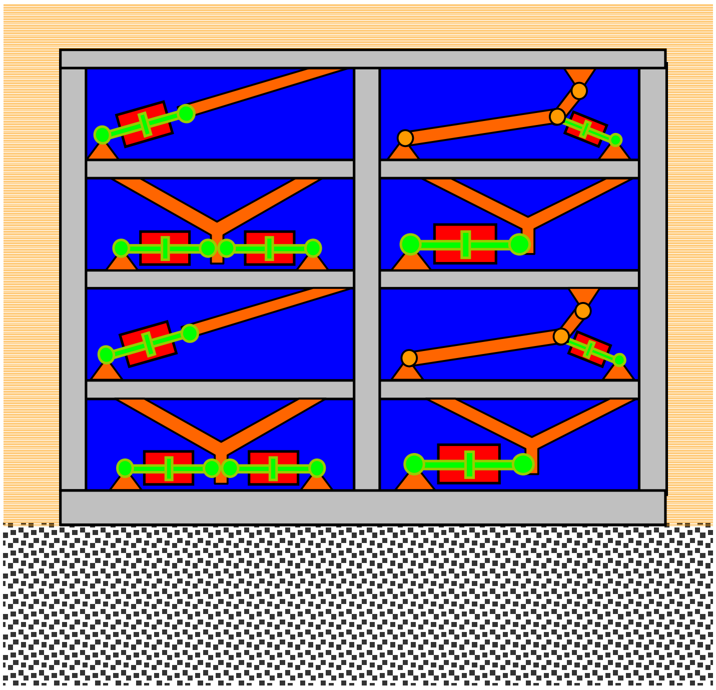


## Products and Technical Information



MAURER SÖHNE
Innovations in steel
Since 1876

# MAURER
# Seismic Building Protection



## CONTENTS

# 1. Introduction

It is a statistical fact that every year 150 - 200 earthquakes with a magnitude of up to 7.0 occur worldwide. Fifteen of those seismic attacks exceed even this magnitude. The severe earthquakes of 1999 caused approximately 25,000 victims and financial damage was estimated at US-$ 20 billion (Izmit /Turkey), US-$ 14 billion (Athens/Greece) and US-$ 150 million (Taiwan) respectively. As there is no change in this trend in sight for a decrease in the frequency or severity of the attacks, the sensitivity of modern infrastructure calls for effective seismic protection systems.

Fig. 1: Taiwan earthquake 1999

One option to protect structures against earthquakes is Seismic Isolation, a structural design approach to mitigate earthquake damage potential.
The idea is that of reducing the seismic input into the structure instead of increasing its resistance to it.

This approach was already proposed in the early years of the last century. Precisely, the first patent application for seismic isolation was granted to Mr. J.A. Calantarients in 1909. His idea was to install a sliding layer between the building and its foundation to allow the building to slide during an earthquake. Thusly, the energy transmitted to the building itself is reduced.

Fig. 2: Izmit earthquake 1999

During the last 25 years, many types of devices have been developed to effect a resilient connection between foundation and building and achieve the goal of uncoupling the structural prevailing mass from the ground motion.

In practice, the principle of Seismic Protection for high buildings is that of allowing certain seismic displacements between each floor, but limiting the maximum displacement to a certain well defined value, which is still acceptable for the structure.

Figure 3 below shows the effects of a seismic attack on both a non-protected and an protected structure. Many non-protected buildings have fundamental periods of 0,2-0,5 sec, i.e. the same fall within the typical range of high spectral acceleration (i.e. where the maximum energy content of the response spectrum is concentrated). Thus, the non-protected buildings undergo resonance that results in dramatic amplification of ground accelerations within the structure as well as large inter-storey displacements. In the case of an protected building, the resonance effects can be avoided, kinetic energy is converted into heat within seismic devices and the building moves smoothly without showing appreciable structural deformations or strees overloads.

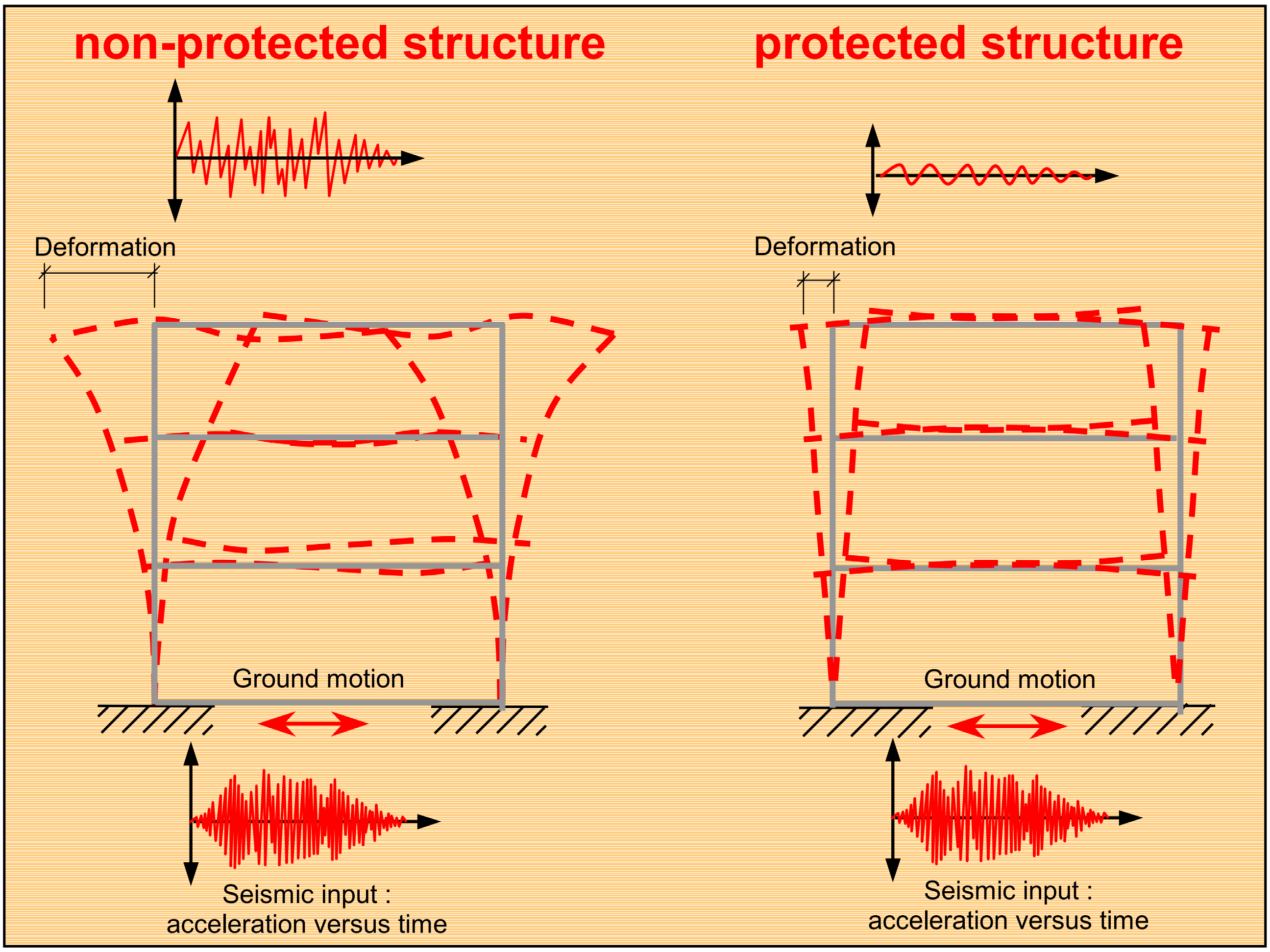



Fig. 3: Displacements and deformations of a non-protected and of an protected structure

**The three fundamental functions of a seismic protection system are:**

1. Transmission of horizontal forces (Fig. 4) between the single floors.
2. Allowance of displacements on the horizontal plane (Fig. 5).
3. Dissipation of substantial quantities of energy (Fig. 6).

These functions can be realised by so called ***dampers or partly by shock transmission units***.

The first function means that the protection system acts as a restrainer system, i.e. transfers horizontal forces in the intended location, connecting the upper floor to the lower floor (Fig. 4).

The second function allows defined displacements within the devices or allows horizontal deformations of the structure between the single floor respectively. This horizontal flexibility reduced the attracted amount of seismic displacement energy, which would enter the building if it would be regid (Fig. 5).

The dissipation of energy limits relative displacement of the single floor levels and provides better structural control with bigger safety for the structure (Fig. 6).

The purpose of the self-centring capability requirement – return of the structure to former neutral mid position - is provided automatically by the available structural stiffness itself. The function of flexibility and energy dissipation is just provided by dampers. In case shock transmission units are provided, the function one (horizontal force transmission) is granted, but the structure will just be stiffened and will attract more seismic energy, while the device is not allowing any displacement or flexibility at all. Therefore the shock transmission units application field is restricted to some specific projects and to minor seismic inputs.

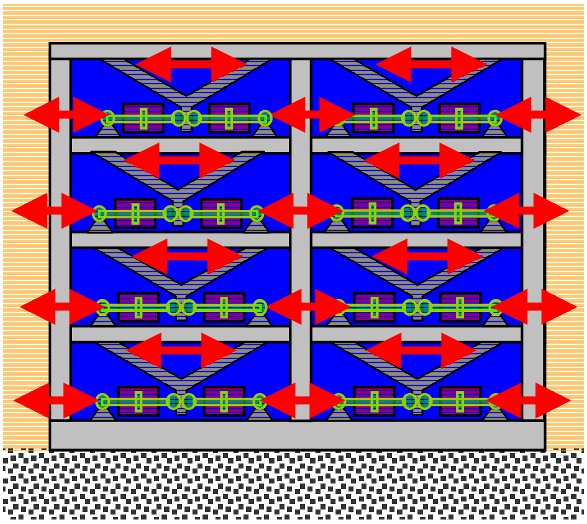


Fig. 4: Horizontal force transmission by devices

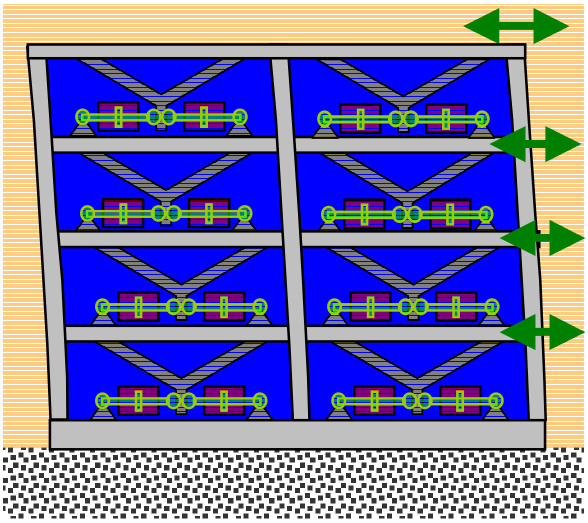


Fig. 5: Horizontal displacements between the single floors are desired

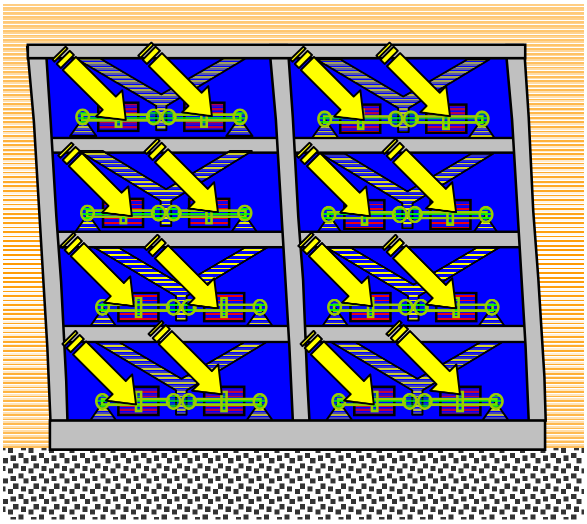


Fig. 6: Energy dissipation through protection devices

## 2. Products for Seismic Protection of Buildings

In the field of Seismic Building Protection MAURER SÖHNE offers the following hardware:

**2.1 Seismic Shock Transmission Units (MSTU)**
**2.2 Seismic viscous dampers (MHD and MHD-R)**

Creating hybrid solutions that combine MSTUs with MHDs might be reasonable in some cases, but depends on final detailed structural calculations.

All below mentioned devices are maintenance free.

## 2.1 Technical description of shock transmission units (MSTU) for seismic and traffic applications

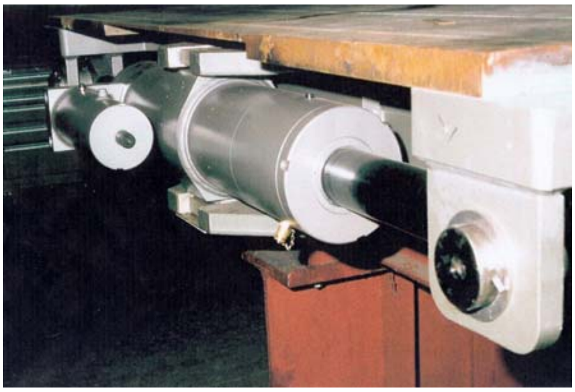


Fig. 7: MSTU integrated into structure

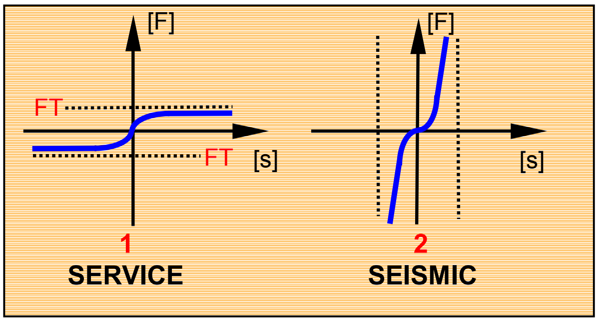



Fig. 8: Force [F] - displacement [s] – plot without force limiter

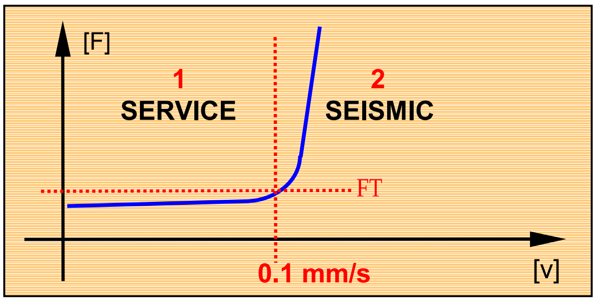



Fig. 9: Force [F] - velocity [v] – plot without force limiter

Fig. 10: Finally assembled MSTU

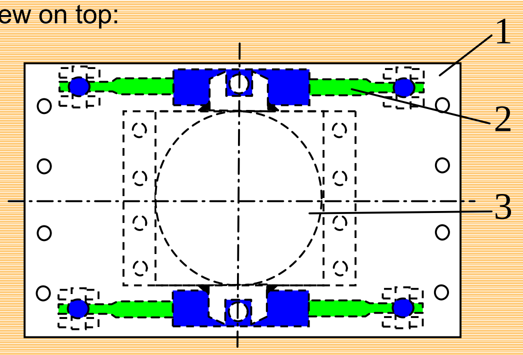
MSTU - MAURER shock transmission units are hydraulic devices (Fig. 7) to connect structural parts rigidly together in case of sudden appearance of fast relative displacements due to earthquake, traffic, wind, etc.. During service these devices react with an insignificant response force due to thermal or creep/shrinkage displacements.

In literature often alternative names are used for such kind of devices, e.g. Lock-Up Device (LUD), Rigid Connection Device (RCD), Seismic Connectors, Buffers or similar.
But not all of these devices react in a similar way. Most of these devices don´t have the important force limiter function, which is described on following page for the MSTL.
Depending on the displacement velocity, the MSTU reacts with a certain nominal response force (Fig. 8).
Very slow displacements due to temperature changes, and creep/shrinkage are causing minor response forces FT within the MSTU (see plot 1 in Fig. 8+9). The fluid inside the MSTU is flowing from one piston side to the other within the hydraulic cylinder.

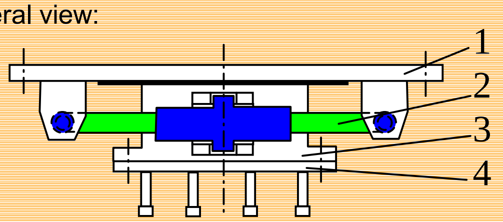
During occurring sudden impact accelerations due to e.g. an earthquake or braking actions of vehicles, which result in greater relative displacement velocities between super- and substructure above approximately 0.1 mm/s, the MSTU reacts with a intense increase of its response force (see plot 2 in Fig. 8+9). The device is blocking any relative displacement between the connected structural parts. In case the real occurring energy input is resulting in higher response forces than the nominal design force of the MSTU, the device will still block till the overload is destroying the MSTU. The hydraulic synthetic fluid is not able to get from one piston side to the other at these great displacement velocities.

# General characteristics of MSTUs

View on top:




Lateral view:




1 = sliding plate   2 = MSTU
3 = pot bearing   4 = anchor plate

Fig. 11: MSTU integrated into a sliding pot bearing

MSTU can also be integrated into structural parts or sliding bearings like pot bearings (Fig. 11).
So the sliding bearings are moveable during service load case and behave like horizontally rigid devices in case of an earthquake or similar impacts.

$$F = C \times v^{\alpha}$$

F = MSTU response force
C = Constant value characteristical for MHD
v = seismic displacement velocity
**a** = damping exponent ≈ 0,5-2

=> due to the great a value the MSTU response force is mainly depending the displacement velocity as the term **"v^a"** increases quite much in case of high velocities.

Fig. 12: MSTU response force equation

**Characteristics of a MSTU:**

- During service conditions the devices are not pre-tensioned and the fluid is under no significant pressure.
- Automatic volume compensation of the fluid caused by temperature changes is achieved without pressure increase inside the devices. Any compensation containers are located inside. On request they can also be located outside.
- No maintenance works necessary. Visual inspection is recommended during the periodic bridge inspections or after an earthquake respectively.
- The devices are not prone to leaking as special high strength hydraulic sealing rings are used like for Caterpillars, automobile industry and similar machineries. On request prove tests can be carried out.
- Rapid response force development according to equation in Fig. 12. Very little elasticity of 2-5% depending on request.
- Range of temperature: -40°C to 70°C.
- Small dimensions and simple installation.
- Depending on request spherical hinges are installed at both device ends to accommodate installation tolerances.

# Preliminary dimensions and anchoring of MSTUs

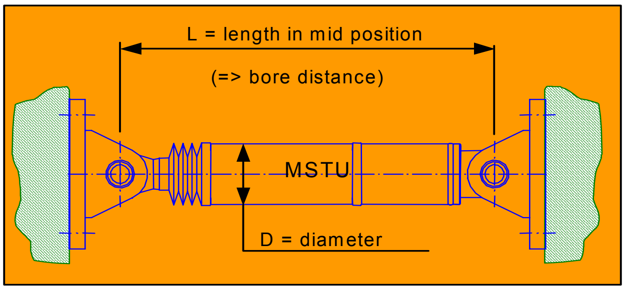



Fig. 13: Sample for installation position of MSTU

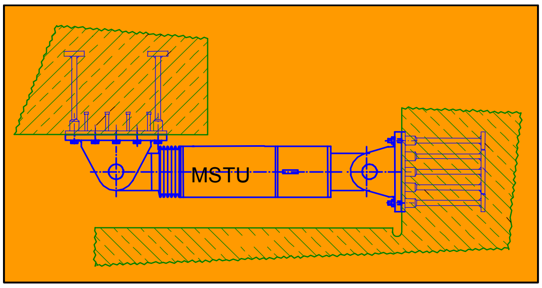



Fig. 14: Alternative installation position of MSTU

**Preliminary dimensions below are valid for connection shown in Fig. 15:**

| axial force [kN] | maximum stroke [mm] 100 | | 250 | | 500 | | 750 | | 1000 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | D [mm] | L [mm] | D [mm] | L [mm] | D [mm] | L [mm] | D [mm] | L [mm] | D [mm] | L [mm] |
| **250** | 171 | 815 | 171 | 1175 | 171 | 1800 | 171 | 2425 | 203 | 3100 |
| **500** | 203 | 960 | 203 | 1265 | 203 | 1890 | 203 | 2515 | 229 | 3190 |
| **700** | 229 | 1145 | 229 | 1400 | 229 | 2025 | 229 | 2650 | 267 | 3325 |
| **1000** | 267 | 1210 | 267 | 1450 | 267 | 2075 | 267 | 2700 | 318 | 3375 |
| **1500** | 318 | 1375 | 318 | 1600 | 318 | 2195 | 318 | 2820 | 368 | 3495 |
| **2000** | 368 | 1515 | 368 | 1740 | 368 | 2280 | 368 | 2905 | 394 | 3580 |
| **2500** | 394 | 1635 | 394 | 1860 | 394 | 2370 | 394 | 2995 | 445 | 3670 |
| **3000** | 445 | 1780 | 445 | 2005 | 445 | 2450 | 445 | 3075 | 508 | 3750 |
| **4000** | 508 | 2090 | 508 | 2315 | 508 | 2690 | 508 | 3305 | 559 | 3980 |
| **5000** | 559 | 2270 | 559 | 2495 | 559 | 2870 | 559 | 3420 | 610 | 4095 |
| **6000** | 610 | 2485 | 610 | 2710 | 610 | 3085 | 610 | 3570 | 680 | 4245 |

The above mentioned dimensions can change in final design depending on detailed request to the devices.
Also the anchor support sizes are not included yet.

The devices can also be delivered with the entire anchoring system like anchor supports and tension anchors as well. The design of the anchoring will then be individually adapted to the designers wishes.
All dimensions are finally adopted to the structure and have to be confirmed by Maurer.

## 2.2 Seismic Viscous Dampers (MHD and MHD-R)

MAURER viscous dampers are devices (Fig. 16), which enable displacements (thermal changes, creep, shrinkage, etc.) during service conditions without creating significant response forces, but dissipate huge amounts of energy during sudden occurance of dynamical seismic energy input, and the energy is been converted into heat. These devices are usually acting in horizontal direction and are not transmitting vertical loads.

Fig. 16: MHD with transport brackets

Very slow displacements e.g. temperature changes, create insignificant response forces FT within the MHD (see **1** in Fig. 17+18).

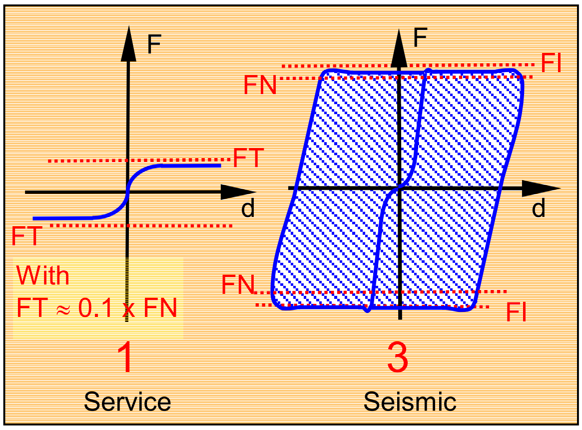



Fig. 17: Force [F] – displacement [d] - plot

When sudden impact accelerations occur between the linked structural sectors due to seismic energy or wind, inducing displacement velocities in the range of approximately 0.1 mm/s to 1 mm/s the MHD blocks and behaves rigidly.
After exceeding a defined energy input, the MHD is forced to overstep the maximum defined response force FN, e.g. during load case seismic, a integrated “intelligent” control mechanism enables relative displacements between the connected parts, but with still constant response force FI, which insignificantly bigger than FN. The very special feature is that FN is independent from the displacement velocities (see 3 in 17+18). During these displacements the special control mechanism pilots the fluid flow very exactly from one piston side to the other in order to achieve this constant response force (Fig. 19).

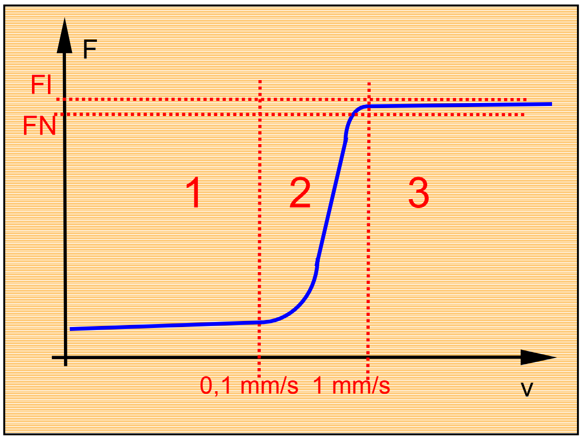



Fig. 18: Force [F] - velocity [v] – plot

On one hand the designer can be sure that a maximum of the induced energy into the structure is dissipated and on the other hand the maximum response force of the MHD acting onto the structure is well known independently how severe the seismic event may be. From there the structure can be easily calculated for this constant response force, and high safety margins are realized in a very economical manner.

The MHD-R type has got an additional inner re-centring spring, means it develops while it is displaced from the neutral position a certain spring force, which is used to push back the structure during and after an earthquake into the mid position. The function equation is shown in Fig. 20 and 21. The re-centring function is decreasing the energy dissipation capability.

The integrated spring can substitute the re-centring capacity of the in some special projects

The efficiency (up to 96%! For a MHD), means the capability to dissipate energy, is much higher for the MHD than for any other available damper. The MAURER viscous dampers offer a great opportunity for perfect damping adaptation to the structural requirement with biggest possible safety margins, while being still very economical.

$$F = C \times v^a$$

F = MHD response force
C = Constant value characteristic for MHD
v = seismic displacement velocity
**a** = damping exponent < 0.02 (2%)

⇨ due to the low a value the MHD response force is independently acting from the displacement velocity as the term “$\mathbf{v}^a$” runs against “**1**”

Fig. 19: MHD response force equation

$$F_R = A + k \times d + C \times v^a$$

$F_R$ = MHD-R response force
A = constant for pre-compression force
k = spring constant of integrated spring function
d = displacement
C = Constant value characteristic for MHD-R
v = seismic displacement velocity
a = damping exponent < 0.02 (2%)

Fig. 20: MHD-R response force equation

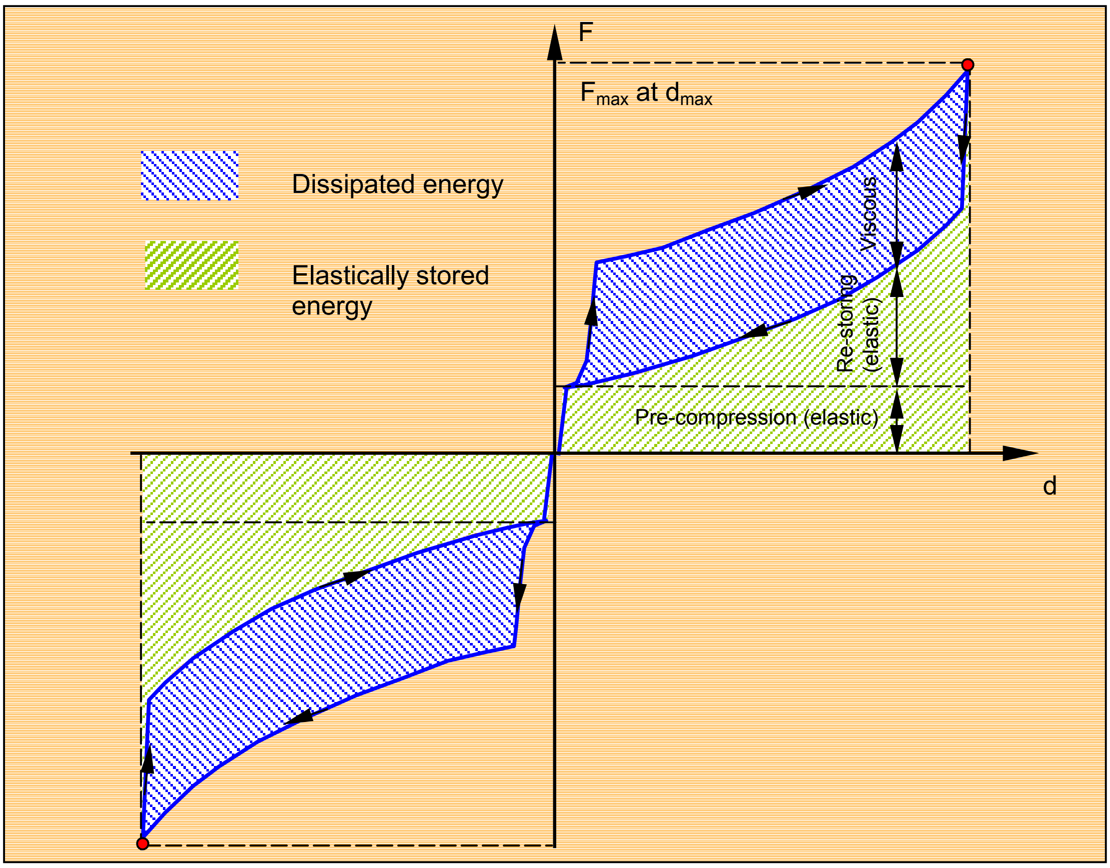



Fig. 21: Force [F] – displacement [d] – plot of a MHD-R

The Maurer viscous dampers (MHD and MHD-R) are available in any sizes. The size is individually adapted to the request. The below mentioned sizes are just for information and will be individually adapted!

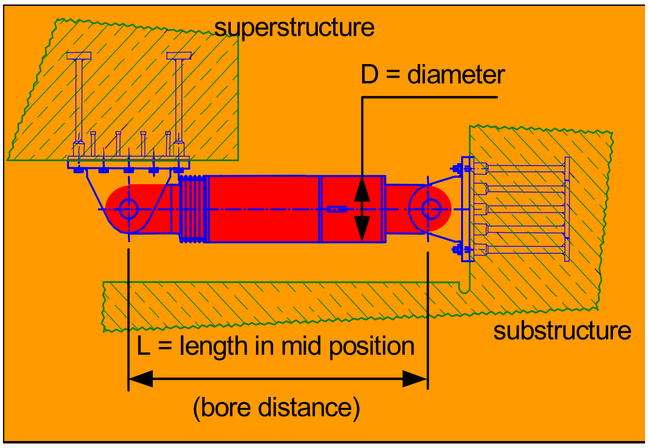



Fig. 22: Sample for anchoring of device to super- and substructure

Fig. 23: Sample for anchoring of device to concrete and steel structure

| axial force [kN] | maximum stroke [mm] 100 D [mm] | 100 L [mm] | 250 D [mm] | 250 L [mm] | 500 D [mm] | 500 L [mm] | 750 D [mm] | 750 L [mm] | 1000 D [mm] | 1000 L [mm] |
|---|---|---|---|---|---|---|---|---|---|---|
| **250** | 171 | 815 | 171 | 1175 | 171 | 1800 | 171 | 2425 | 203 | 3100 |
| **500** | 203 | 960 | 203 | 1265 | 203 | 1890 | 203 | 2515 | 229 | 3190 |
| **700** | 229 | 1145 | 229 | 1400 | 229 | 2025 | 229 | 2650 | 267 | 3325 |
| **1000** | 267 | 1210 | 267 | 1450 | 267 | 2075 | 267 | 2700 | 318 | 3375 |
| **1500** | 318 | 1375 | 318 | 1600 | 318 | 2195 | 318 | 2820 | 368 | 3495 |
| **2000** | 368 | 1515 | 368 | 1740 | 368 | 2280 | 368 | 2905 | 394 | 3580 |
| **2500** | 394 | 1635 | 394 | 1860 | 394 | 2370 | 394 | 2995 | 445 | 3670 |
| **3000** | 445 | 1780 | 445 | 2005 | 445 | 2450 | 445 | 3075 | 508 | 3750 |
| **4000** | 508 | 2090 | 508 | 2315 | 508 | 2690 | 508 | 3305 | 559 | 3980 |
| **5000** | 559 | 2270 | 559 | 2495 | 559 | 2870 | 559 | 3420 | 610 | 4095 |
| **6000** | 610 | 2485 | 610 | 2710 | 610 | 3085 | 610 | 3570 | 680 | 4245 |

Fig. 24: Sizes for MHD and MHD-R devices

The above mentioned dimensions (Fig. 24) can change in final design depending on detailed request to the devices (displacement, re-centring, damping exponent). Also the anchor support sizes are not included yet. The devices can also be delivered with the entire anchoring system like anchor supports and tension anchors (Fig. 22 and 23) as well. The design of the anchoring will then be individually adapted to the designers wishes.

Seismic protection by energy dissipation with MAURER dampers **- up to 61% damping -** represent todays most effective tools in the hands of design engineers in seismic areas to limit both relative displacements as well as transmitted forces between adjacent structural elements to desired values. This means being able to control at will the structure´s seismic response and ensures the required degree of protection in a still economical manner. Finally the stress upon the structure is decreased also, which brings structural cost reduction along in addition!

# 3. Seismic Protection Systems for Buildings

The protection system will be adapted to the structural space conditions and to the seismic design impact or design engineers requirements.
The available hardware components always allow to achieve the technical best solution, while still being within a acceptable economical range.
The above listed components allow many different solutions for protection systems. To give an overview, we showed up below four examples depending on the seismic input intensity, structural space and requirements.

The proposed systems are just to give an idea what is possible. Finally there is no general rule existing that a certain system is always the best for all structures and any seismic input intensity. Means depending on the structure and the seismic input the seismic protection system has to be set together by the different shown components to maximize its efficiency to the highest possible level.

## 3.1 Diagonal Bracing

For low seismic input and low ground peak accelerations in the range of 0,1 the superstructure is simply protected by MSTUs or MHDs by diagonal bracings, as shown in Fig. 25.

The number and size of bracings with MSTUs or MHDs is depending on the seismic input, the requested horizontal stiffness, the acceptable horizontal displacement and the amount of energy to be dissipated.

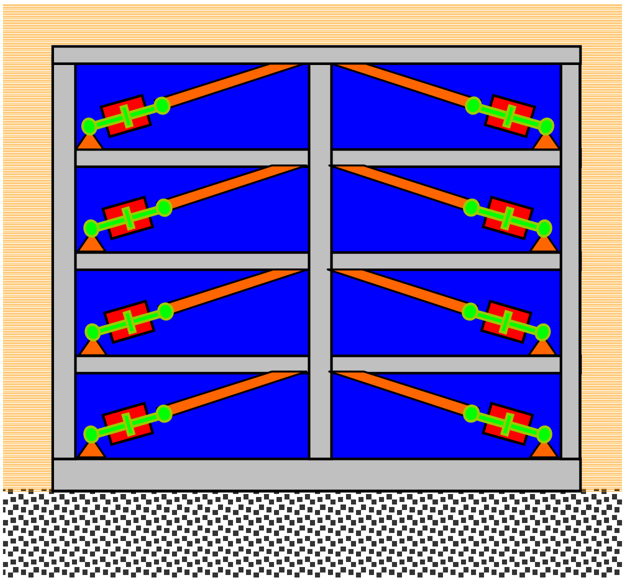


Fig. 25: Diagonal bracing with brace and integrated MSTU or MHD

## 3.2 Horizontal Bracing

For low to medium seismic input and low ground peak accelerations in the range of 0,15 to 0,25 the superstructure is simply protected by MHDs in horizontal bracings, as shown in Fig. 26.

The number and size of bracings with MSTUs or MHDs is depending on the seismic input, the requested horizontal stiffness, the acceptable horizontal displacement and the amount of energy to be dissipated.

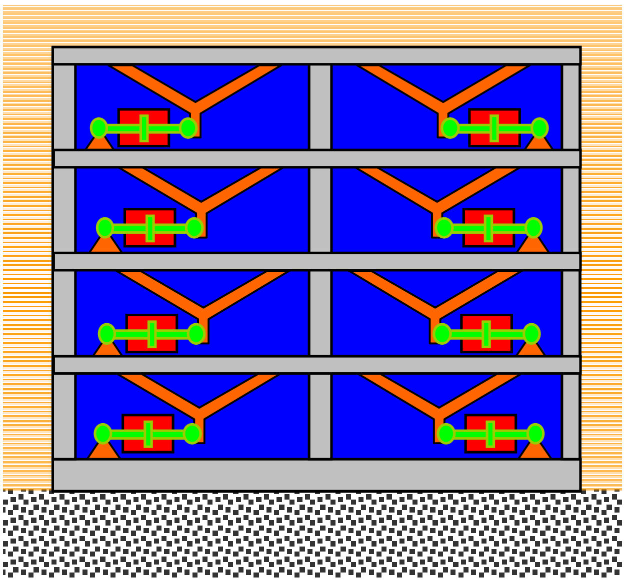


Fig. 26: Horizontal bracing with brace and integrated MHDs

## 3.2 Double horizontal bracing

For severe seismic input and great ground peak accelerations above 0,3 the superstructure is protected best by big MHDs in horizontal bracings, as shown in Fig. 27.

The number and size of bracings with MSTUs or MHDs is depending on the seismic input, the requested horizontal stiffness, the acceptable horizontal displacement and the amount of energy to be dissipated.

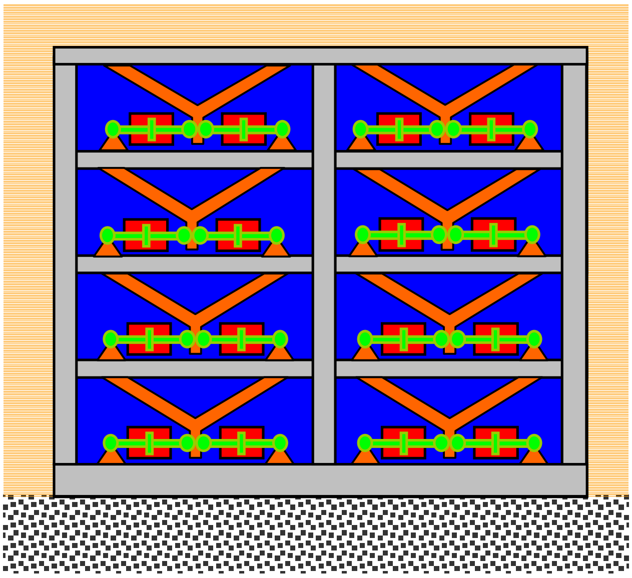


Fig. 27: Horizontal double bracing with brace and integrated MHDs

## 3.1. Diagonal hinge bracing

For severe seismic input and great ground peak accelerations above 0,3 the superstructure is protected best by big MHDs in combination with hinge bracings, as shown in Fig. 28.

The number and size of bracings with MSTUs or MHDs is depending on the seismic input, the requested horizontal stiffness, the acceptable horizontal displacement and the amount of energy to be dissipated.

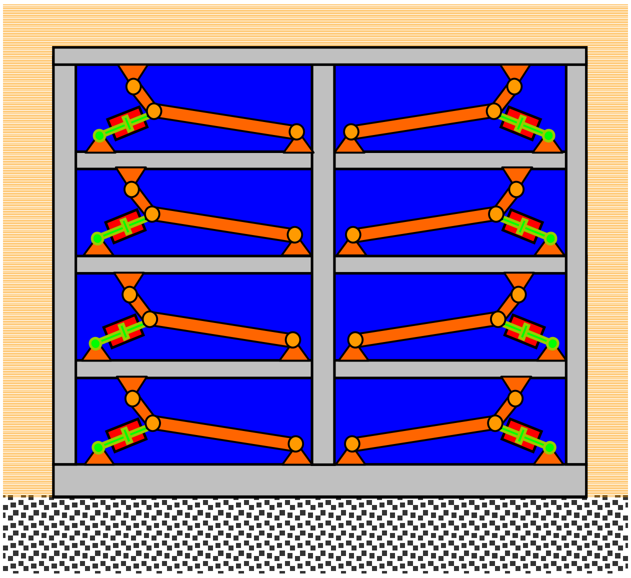


Fig. 28: Diagonal hinge bracing with brace and integrated MHDs

On request MAURER will deliver the entire bracing together with the dampers and/or shock transmission units.
To avoid shipping of too much steel, we are also prepared to provide just the drawings with calculations and the bracing is fabricated by local steel companies.

## 4. The way to the ideal Seismic Protection System

The especially adapted MAURER seismic protection system (Fig. 29) ensures full service abilities after the nominal earthquake and structural damages are totally avoided. Hence the structure is immediately ready for service again and for possibly following further earthquakes.
Depending on request for the single components the design can be done according to EURO NORM, AASHTO, BRITISH STANDARD, DIN or any other standard.

Despite the fact that some guidelines for seismic engineering have been implemented in the last few years, every structure is unique, has to be individually calculated, and requires tailor made components.

MAURER is offering extensive general and individual consulting for the seismic components, as well as for the principle design of structures. On request MAURER performs a *non-linear time history analysis* (see also page 16) of the entire structure with the input data of the designer.
By application of the special seismic protection system of MAURER the structure´s design needs not be changed.

On account of the above mentioned reduced forces, as energy is dissipated, the structural safety margins rise considerably. In order to save costs, it can also be considered to weaken the structure to the permissible stress limit by doing new structural calculations with the revised response forces. In that case, the actually requested safety margins stay on the same level as before without seismic isolation system.
The advantages of a seismic isolation system (Fig. 30) are obvious and satisfy protection and economic requirements.

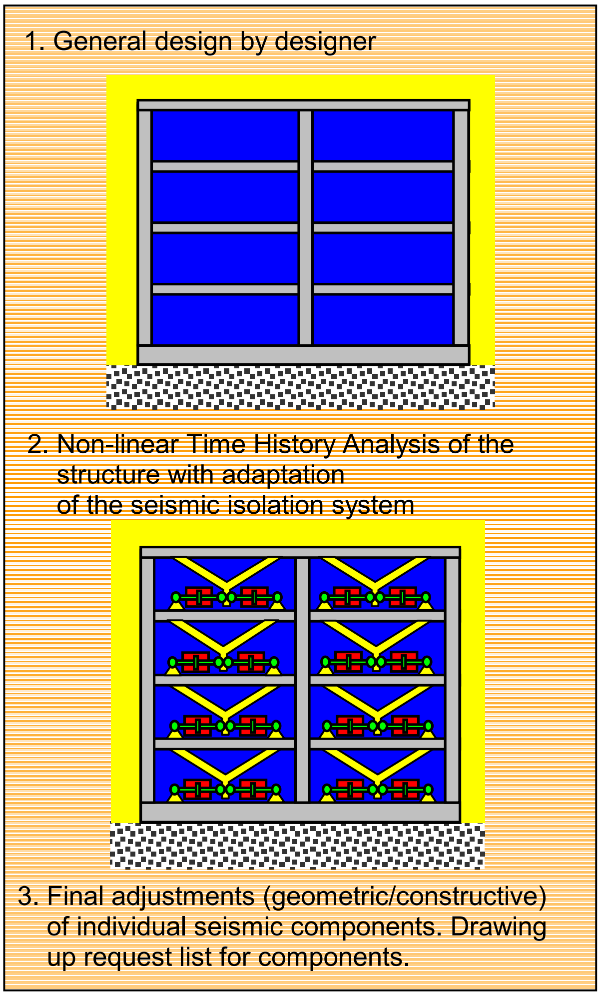



Fig. 29: Steps to built up a seismic isolation system

**Advantages:**

- Maximum seismic protection with great safety margins,
- Compared to other methods like *strengthening* normally only minor changes,
- No structural damages due to the design earthquake => prepared for following earthquakes and ready for service,
- Normally only minor changes of the structure are necessary by implementing a seismic isolation system,
- Components can be easily installed,
- Approved by tests and in service for many years.

Fig. 30: Advantages of a MAURER Seismic Protection System

## 5. Information for a non-linear Time History Analysis

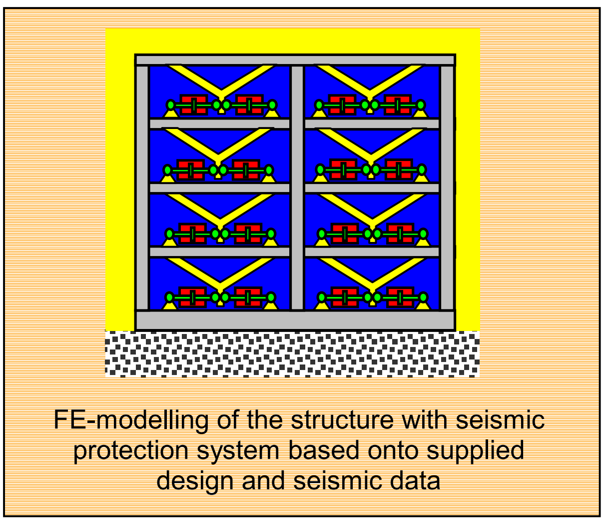
On request, MAURER SÖHNE carries out a detailed non-linear time history analysis for any kind of structure and will select the seismic protection system that is best possible to satisfy individual requirements.
The analysis is a support for the designer to compare his own one with the one from MAURER.

For a non-linear analysis, the following input data are necessary:

- Design drawings of the structure,
- Data of significant cross sections of deck, abutment and piers (surface; moment of inertia about the main axis of these sections, torsion constant of these sections, transverse shear stiffness).
- Materials (young modulus, shear modulus, density).
- Foundations (dimensions and soil winkler´s modulus, translation and rotation stiffness of equivalent springs).
- Seismic input: response spectre and representative site accellerograms.
- Loads (dead loads, maximum live loads, live loads under seismic conditions).
- Admissible actions in most significant locations like foundation, floors etc. (admissible bending moments, shear+axial forces, and displacements).
- Special requirements of the design engineer.

Advantages of a non-linear time history analysis:

- Exact determination of structural displacements.
- Exact calculation of the seismic response forces acting onto the devices and structure.
- Optimised adaptation of the seismic protection system with respect to efficiency and economical benefits.
- Proof for best possible seismic protection.
- Exact evaluation of real structural safety factors.
- **Design engineer is able to compare his own calculations with the analysis in order to get his results confirmed.**
- Possible economical benefits due to savings in the design.



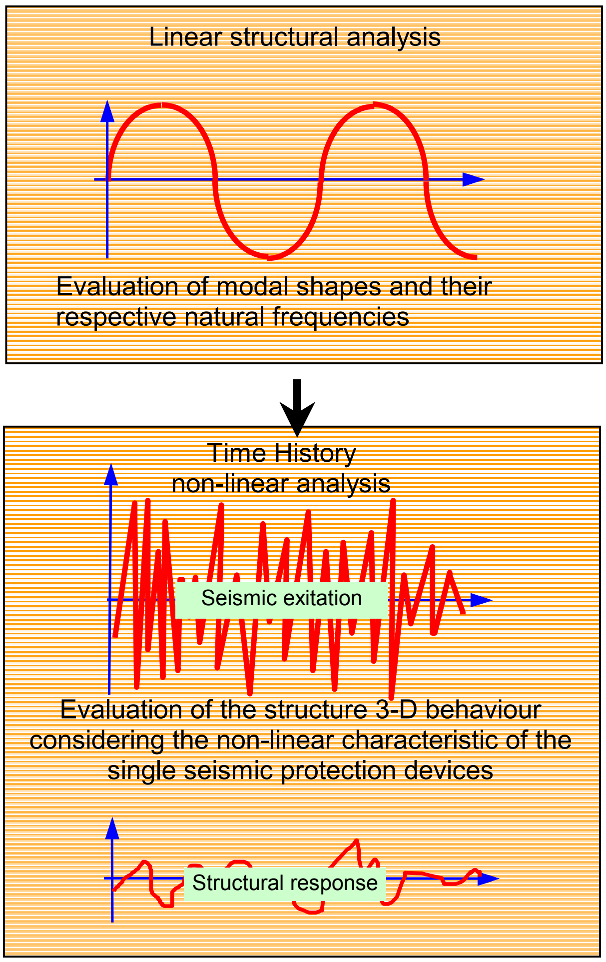




Fig. 31: Steps to be carried out for a non-linear analysis