3. ACED DEVICES AND SECAF SUPPORTS FOR THE CONTROL OF STRUCTURE, PIPE NETWORK AND EQUIPMENT BEHAVIOUR AT SEISMIC MOVEMENTS IN ORDER TO ENHANCE THE SAFETY MARGIN

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1. INTRODUCTION

In order to enhance the safety margin of structure, pipe networks and equipment associated to the existing NPP's, the classic consolidation solutions are very expensive and many times, impossible to be implemented.

Structures, pipe networks, systems and equipment have geometries imposed by the basic construction requirements, operating and safety requirements and their modifications is not always possible.

In order to enhance the strength capacity of (new or old) structures, systems and equipment mechanical devices with controlled elasticity and damping (ACED) have been designed, constructed and experimented. These devices are capable to support very large static loads over which dynamic loads (shock, vibration and seismic movements) overlap (which are damped).

To encrease the strength capacity of (new or existing) pipe networks and equipment connecting with pipes, SECAF supports that allow displacements from thermal expansions with low reaction force have been designed, constructed and experimented. SECAF supports are capable elastically to take permanent loads over which shocks, vibrations and seismic movements (which are damp) overlap.

ACED devices and SECAF supports can be used to rehabilitate the existing NPP's with law financial costs and an encrease of their strength capacity up to 100% under seismic movements, shocks and vibrations.

ACED devices and SECAF supports do not require maintenance, are not affected by presence of a radiation field and their estimated service - life is similar to the NPP's.

2. THE USE OF ACED DEVICES TO ENHANCE THE STRUCTURE SAFETY LEVEL

2.1. GENERAL

The current solution for rehabilitating buildings affected by a seismic event consists of consolidating the structure by the procedure of lining the columns, beams, walls, or inserting of new reinforcing elements so that the consolidated structure withstand and take over the designed seismic loads.

Socially and environmentally this solution has the disadvantage that it requires more labor, it produces large quantities of waste that has to be transported and disposed, it generates stress and negatively influences to the social activity for a long period of time. In addition the solution is expensive and requires a long time for implementation.

On the other hand, in Romania the buildings constructed after 1977 (when the last major earthquake occurred in the region of Vrancea), though designed according to a new concept regarding the level of designed seismic forces determined on basis of seismically induced energy dissipation by means of controlled plastic hinges and the limitation of relative interstore displacements, have not yet been "tested" under a major actual earthquake.

The paper presents the concept and experimental results regarding the mechanical devices capable of providing passive structural control of buildings response to seismic loads.

These mechanical ACED devices can be used both for efficiently and quickly consolidating any type of existing buildings and erecting new existing constructions.

The devices can be easily manufactured and their application will result in an increase of the quality of the consolidation work, in a reduction of work amount on site, in the protection of the environment and in efficient control of the behavior of the new and existing building structures' during earthquakes.

2.2. PASSIVE CONTROL OF BUILDINGS

Structure passive isolation against shocks and vibrations generated by dynamic loads consists of the insertion of some elements with elastic and damping properties between the excitation source and the building structure.

The natural period of the protected building will increase due to the elastic elements, being shifted away from the dominant period of the seismic excitation and the large damping will prevent the amplification of vibrations including those in the vicinity of the resonance frequencies.

The force transferred to the structure decreases while the displacements increase. One can say that the design of structures having isolation systems represents a trade off between the loads and displacements.

The passive control system can be achieved with external devices, by isolating the structure base and/or with internal devices embedded into the structure as reinforcing elements (i.e. bracing, walls).

2.3. ADJUSTABLE CONTROLLED ELASTICITY AND DAMPING MECHANICAL DEVICES FOR STRUCTURAL RESPONSE CONTROL

The systems and devices for the passive control of structure dynamic response to seismic inputs carried out by now, can perform, to a certain extent, an acceptable control of building behavior according to theoretical analysis, experimental testing and analysis of data collected during actual earthquakes based on the behavior of existing isolated buildings.

In spite of the developments and improvements implemented so far, the existing devices show several disadvantages, namely:

- The devices are made of materials (i.e. rubber, elastomers), which change their properties in time due to the aging phenomenon, and consequently they have to be periodically inspected and replaced, when necessary. The static loads taken over by such devices are limited both by the accelerated aging of the material subjected to loads, and the low strength capacity of some device components.
- Building isolation can be done on horizontal plane only due to the fact that the device stiffness on vertical direction is thousand times higher than on horizontal direction.
- The existing devices do not show a strong nonlinear behavior so to avoid the occurrence of shocks.
- The dry friction devices are subject to a high pressure between the contact surfaces which, in time, may result in a local welding and finally in the device locking.

The new types of adjustable controlled elasticity and damping mechanical devices show none of the disadvantages of the classic devices. Moreover, these new devices are capable to adapt their stiffness and damping function to the load level, providing a good control on the structure behavior. ACED devices are made up of elastic blade packages fabricated from high strength austenitic stainless steel thin plates. The elastic blade packages are made of disks and annular plates bound as a sandwich type assembly.

Depending on the device type and on the type of load taking over (either static loads overlapped on the dynamic loads, or dynamic loads only), a device consists of several packages of elastic blades mounted in-series. Each package is composed of a variable number of blades acting in parallel.

The elastic blade packages are subject to normal deformations on their contact surfaces by means of stiff deflective disks with an adequate geometry (spherical, cone - shaped, etc.) required by the desired force - deflection ratio.

Compared to the classical devices, the new ACED devices show the advantage that due to their small size, one can obtain a preset force – deflection ratio, thus providing a nonlinear characteristic in the elastic range of the device components. So, the device is capable of taking over both the permanent gravitational loads and the dynamic loads, without shocks, as well as to dissipate energy.

The damping characteristics are also adjustable depending on the load level in the sense that it is dependent on the static and/or dynamic loads applied on the device. Energy dissipation is mainly due to the radial friction between the elastic blade packages because of the normal forces developed on the contact surfaces.

For the control of structural response to seismic inputs, two types of devices (i.e. ACED-B and ACED-I) were developed.

The two types can be inserted in the building structures or located between the building and the ground for base isolation.

ACED-B (Fig. 3.1) is installed inside the building in order to control the inter-story displacements it provides important seismic energy dissipation and it generates the internal force necessary to revert the structure to the initial position.

These devices can be installed in the structure braces of new or existing buildings as prestressed tendons (Fig. 3.2).

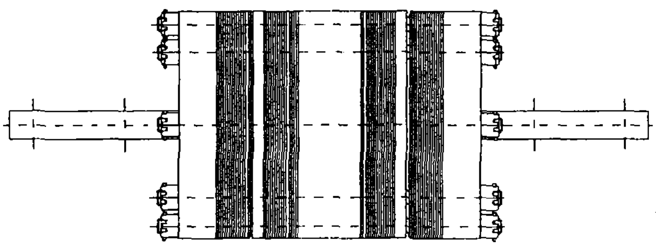


Fig. 3.1 ACED-B device

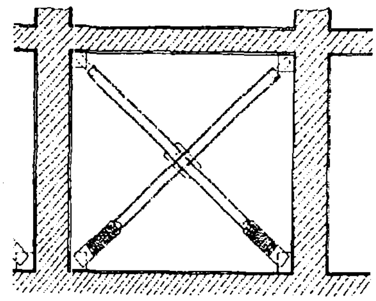


Fig. 3.2 ACED-B installed

Once ACED-B are installed in the braces of new or existing buildings (i.e. the devices are prestressed in order to be operational even when very small deformation occur in the structure), a dissipation of the seismic energy for small and average loads on the building structure occurs during earthquakes although the structure does not reach the plastic range. When the preset deflections corresponding to the displacement inter-story level required by the building type are reached, the stiffness of the devices increases very much according to a preset law, providing the necessary force to maintain the building stability and revert to its initial position.

ACED - I devices (Fig. 3.3 and Fig. 3.4) may be installed either between the buildings basement and foundation (a solution that is preferred in the rehabilitation of monuments as it does not impair their architecture), or between the consolidated substructure of a building and its super-structure (a solution that is preferred when retrofitting or strengthening residential buildings).

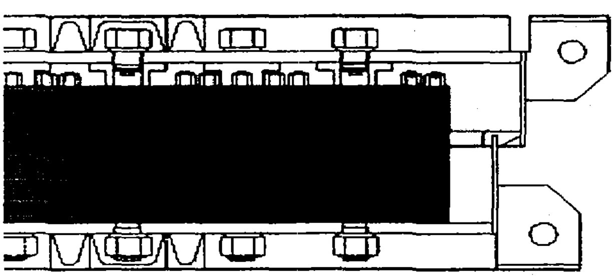


Fig. 3.3 ACED-I device section

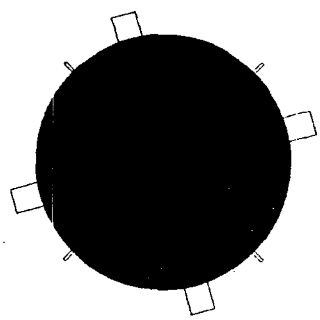


Fig. 3.4 ACED-I device view

The new devices are capable to offer a good isolation on vertical direction as well, which is very important for old and monumental buildings (generally, large-span, low-height buildings).

ACED-I devices can be installed in series making up columns where the vertical and horizontal displacements are controlled by the manufacture of the devices. Between the top of the columns attached to the building basement and the lower part of the columns usually attached to the foundation, it is possible to mount the ACED-B devices in order to control the relative displacements between the building and the ground, increasing the seismic energy dissipation capacity.

2.4. EXPERIMENTAL RESULTS

To evaluate the performances of the new types of devices, two models (i.e. ACED-B and ACED-I) were manufactured. In accordance with their size, they place themselves at the maximum and minimum limit of the devices employed to control the structure behavior.

Austenitic stainless spring steel strips made by SENDVIK (Sweden) were used for the models. These strips are also to be used for the industrial production of the devices.

Fig. 4.1 and Fig. 4.2 show the types of ACED-B devices with 110 mm and 300 mm diameter.

Tests conducted in the "Institute for Solids Mechanics" attached to the Romanian Academy show that the new devices can be manufactured with the required stiffness and high damping capacity.

The paper presents the experimental results obtained with the ACED-B-110 and ACED-B-300 types, which have the elastic strips package made up of 4 central disks and 5 peripheral annular plates. The ACED-B-110 device is 110-mm diameter and the elastic strips package is made of stainless spring steel plate, 12R11 grade, of 0.15 mm and 0.5 mm thickness, manufactured by SENDVIK, Sweden. ACED-B-300 device is 300-mm diameter and the elastic strips package is made from alloy plates (CuNI18Zn27), of 1 mm thickness.

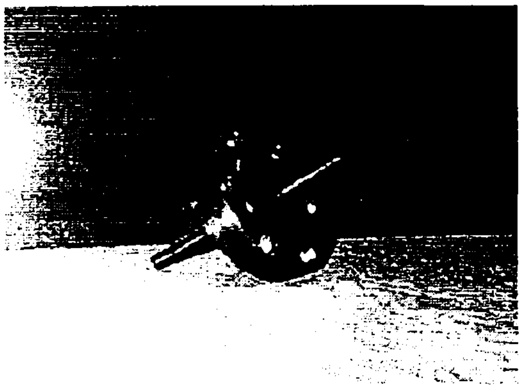


Fig. 4.1 ACED-B device model 110 mm

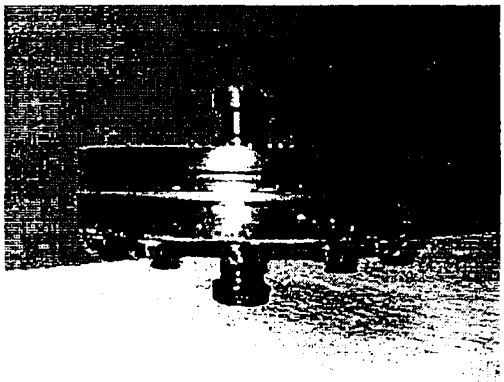


Fig. 4.2 ACED-B model device 300 mm

Fig. 4.3 - 4.6 present the hysteretic behavior and the dynamic response for ACED-B type.

The analysis of the experimental results shows that:

- The force - displacement characteristic shows a nonlinearity controlled by the strips thickness and the deforming disk geometry (Fig. 4.7);
- The relative damping provided by the models of devices, expressed by the dissipated energy per cycle, is about 25% from the elastic energy for a 15 KN pre-load (static load) for ACED-B-300 (Fig. 4.8), and about 11.4% from the elastic energy for a 0

KN pre-load for ACED-B-110 (for 0.5 KN pre-load the relative damping is 17%); damping is strongly dependent on pre-loading.

Fig. 4.3 ACED-B 110 hysteretic loop

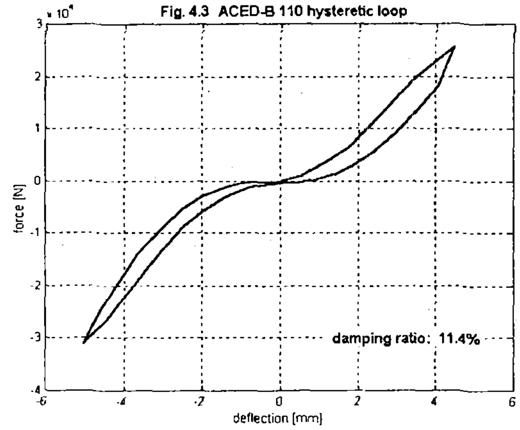


Fig. 4.4. Amplification rate for ACED-B 110 model device

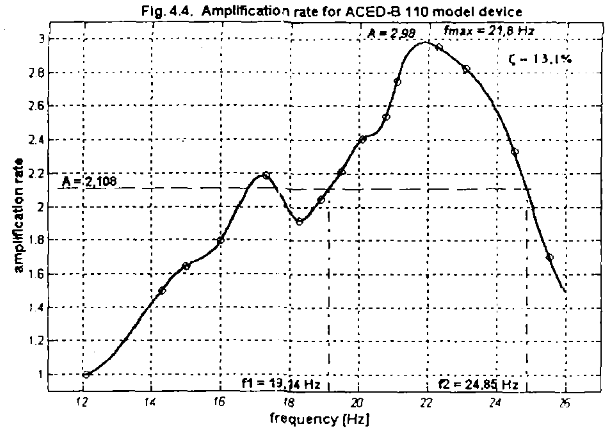


Fig. 4.6. ACED-B 300 hyteretic loop (static load 0 N)

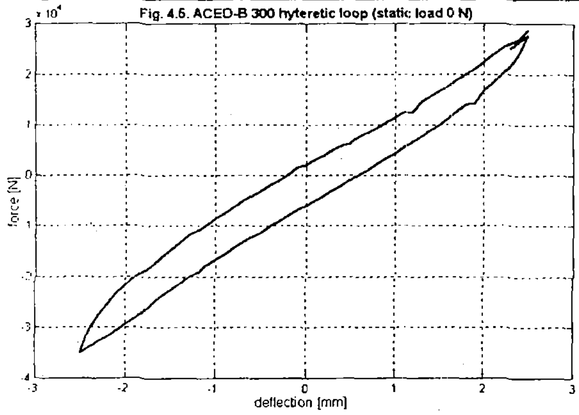


Fig. 4.6. ACED-B 300 hyteretic loop (static load 0 N)

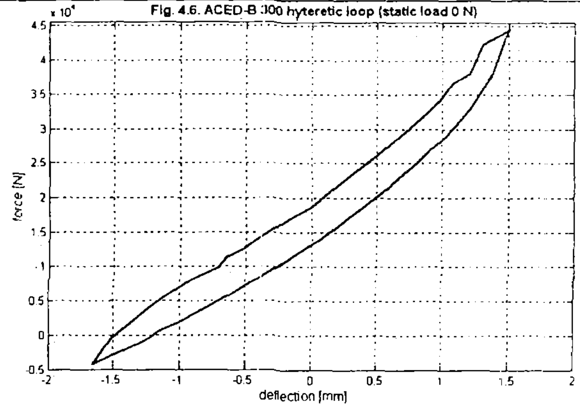


Fig. 4.7 ACED-B 300 model device. Stiffness - static load dependence

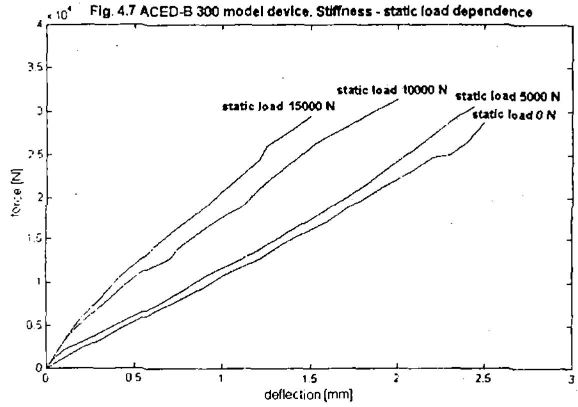
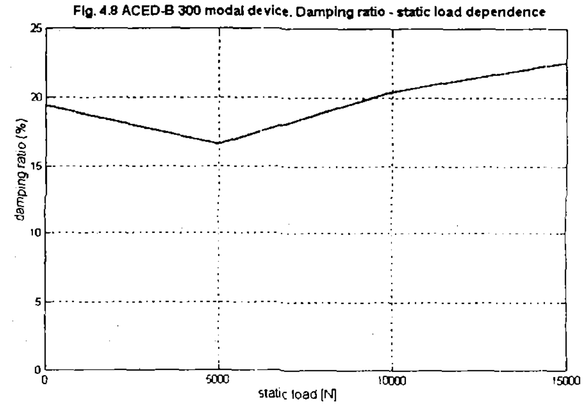


Fig. 4.8 ACED-B 300 modal device. Damping ratio - static load dependence



2.5. CONCLUSIONS

The employment of passive control systems means the accommodation of structures to seismic loads so that the seismic energy is consumed in certain locations (at the structure basis or inside the structure), while the structural elements of the building stay within the elastic strain range. With most of the current passive control solutions, the employed devices are subject to the accelerated aging phenomenon so that after an earthquake the elements that provide the passive control must be inspected and possibly replaced.

ACED devices can be an alternative solution not only for strengthening the existing buildings in order to make them withstand successfully the future earthquakes but also for the erection of new buildings.

The use of ACED devices ensure the control of buildings' response to seismic input and provide the dissipation of the seismic energy for low and average structure loads and the necessary force to prevent the building collapse for large load conditions and to revert to the initial position.

ACED devices allow the construction of structures that can take over the seismic inputs with small loads providing a controlled stiffness increasing with the stress level, as well as dissipate the seismic energy transferred to the building starting with very low levels of strain thus preventing the building structure to reach the post-elastic range.

Strengthening of buildings can be done either by embedding some braces that include ACED-B devices into the existing structure or by inserting some ACED-I devices between the super-structure and the consolidated substructure.

In the near future, the research activity dedicated to the application of ACED devices to the control of the building structure behavior at seismic events, will develop according to the following steps:

- Manufacture of ACED-B and ACED-I prototypes;
- Experimental determination of the stiffness and damping characteristics for the ACED devices and the analytic assessment of their characteristics;
- The compared analysis of the seismic behavior of building types according both to the classical design solution and the new design solution which employs ACED devices embedded in structures;
- Construction of a prototype building equipped by an ACED device and it's testing.

3. THE USE OF SECAF SUPPORTS FOR THE ENCREASE OF PIPE NETWORK, SYSTEM & EQUIPMENT SAFETY LEVEL

3.1. General presentation

The load condition associated to pipe networks and power equipment is strongly dependent on the way in which the thermal expansions are compensated and on the damping of the loads generated by shocks, vibrations and seismic movements.

The new supports, called SECAF, may be employed for new and existing pipe networks in order to reduce the load conditions from thermal expansions, seismic movements, shocks, vibrations, etc. The supports are capable to take over static loads with pre-set deflections, allow thermal expansions with very low reaction forces, damp the shocks and vibrations generated during the explosion of pipe networks and protect the pipe networks against seismic events.

The use of the new supports mean that the loads in the pipe networks and the forces transferred to the supported structures are much lower and the loading cycles of pipe networks are subject to a much lower amplitude, that is the aging phenomenon decreases while the pipe network service life enhances.

With the existing NPP's, the control of such loads by means of SECAF supports, may lead to a 100% reduction of the general stress level condition in the associated pipe networks and power equipment.

In order to minimize the load and stress level in pipe networks and equipment during all the operation regimes, the supports must take over loads in static and dynamic conditions with certain degrees of freedom so that the relative balance condition between the forces and the moments in the supports and the forces and the moments in the associated pipe networks, should get set at their smallest possible values.

For the balance of forces and moments get set at the smallest possible value, both in the pipe network and the supports, the supports must have a controlled elasticity capable to allow the support deflections under static loads, on certain directions, with pre-set reaction forces while their dynamic loads act in paralel with a pre-set damping value.

Supports must allow displacements imposed by the pipe thermal expansions with small elastic reaction force an/or low value pre-set friction force.

Moreover, on the direction of the thermal expansion, the support must have a damping force for the dynamic loads, in order to provide the damping of shocks and vibrations on the other degrees of freedom of the support.

The new type of SECAF supports meet the imposed requirements for a good behaviour of the pipe networks and, with the employment of the new supports instead of the traditional supports, the load condition in the pipe network may reduce by at least 40%.

3.2. Experimental models:

In order highlight the performances of the new types of SECAF supports, two types of experimental models of supports have been designed. Experiments conducted with these two experimental models led to findings for the entire range of supports to be accomplished within the project.

For modeling the "fix points" of fastening the pipe networks, the design called: "SECAF support experimental Model - 1A 0/0/5" has been accomplished to allow elastic displacements on the axial direction of the support (usually, the vertical axis for taking over the permanent self - weight loads) and the displacements on the normal plane of the support axis are blocked. Rotation on axial direction (nonally 2 vertical axis) is free and the rotations on x & y axis in the horizontal plane show moments of elastic reaction.
The controlled elastic distortion is given by two (central and peripherical) sets of elastic blades that intermingle and are pre-fastened by two distorting disks having a spherical or cone - shaped geometry. Attachment to the pipe is usually made by the central screw that pre-tighten the two deforming disks and the attachment to the supporting structure is usually made by a plate, stiffenly connected to the peripherical elastic blades by means of two (upper and lower) rings pre-tightened by screws.

For modelling the "points with displacements from thermal expansions" for fastening the pipe networks, the design called: "SECAF support experimental model - 2A 40/40/10" has been elaborated. The experimental model allows displacements on all the directions in a plane (usually horizontal plane and paralel plane with the pipe axis) of ±40 mm from the thermal expansion with a constant friction reaction force and axial displacements of ±10 mm with an elastic reaction force having a non-linear characteristic.

3.3. Experimental tests:

Experimental tests to determine the stiffness and damping characteristics of support models have been conducted in 5 steps including quasi-static and dynamic loads as well as from thermal expansion, on SECAF - 1A 0/0/5 and SECAF - 2A 40/40/10.

Fig. 3.3.1 and 3.3.4 illustrate examples of some experimental results obtained.

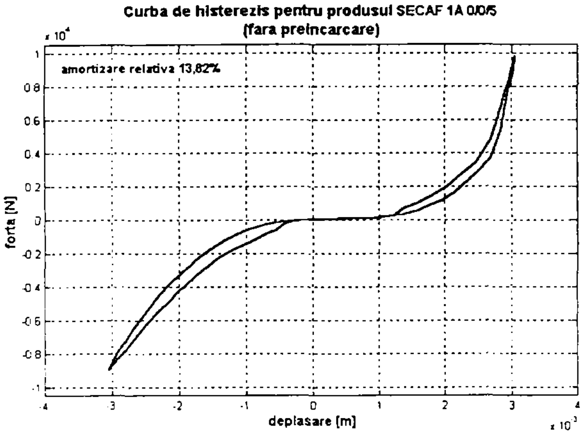


Fig. 3.3.1

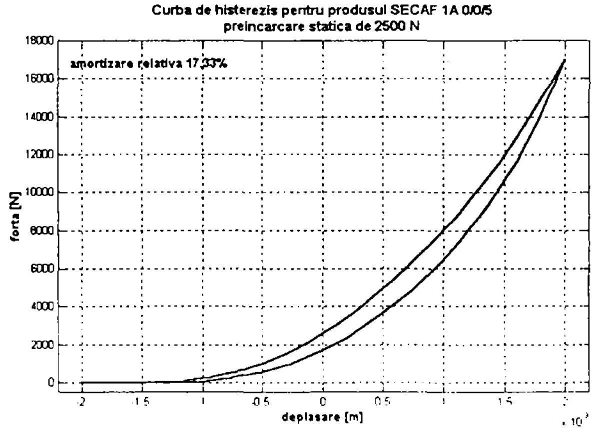


Fig.3.3.2.

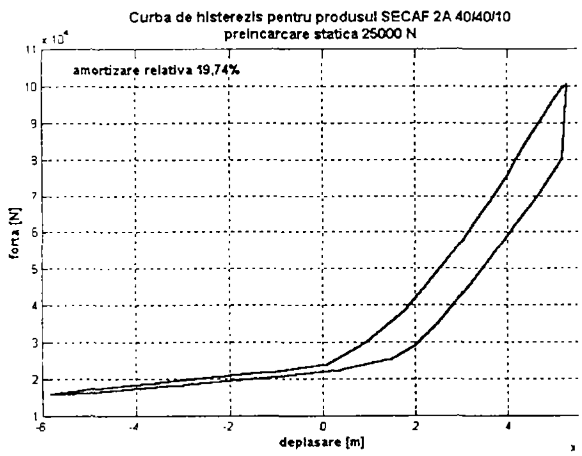


Fig. 3.3.3

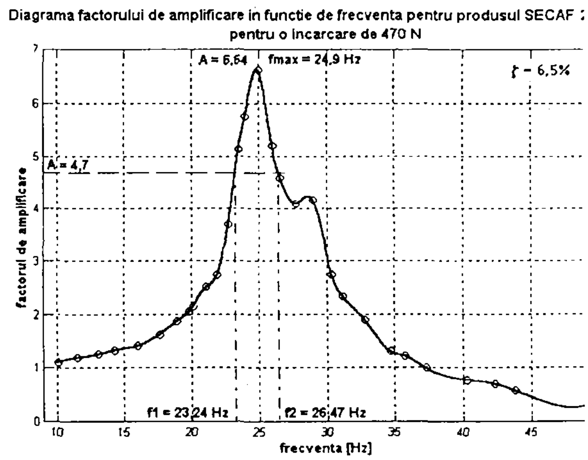


Fig. 3.3.4

3.4. Predicted effects:

The use of SECAF supports in pipe networks and power equipment results in the following effects:

- reduce or eliminate the vibrations generated by the fluid flow inside the pipe lines and by the operation of the pipe network associated equipment;
- reduce the load transfer from the pipe networks and to associated equipment to the supporting structure and vice - versa;
- reduce the load level in the pipe networks supports and the time interval of their variation;
- reduce the seismic load level in the pipe networks by at least 40%;
- encrease the service - life of the pipe networks;
- provide the supply of the necessary supports for the rehabilitation of the thermal and nuclear power plants from the domestic market.

3.5. Results and conclusions:

With SECAF supports the new element is represented by the fact that the static and dynamic loads are taken over by a package of central elastic blades which may move relatively to another peripherical elastic blade package fixed to supported structures.

According to the new design of the supports, the directions the elastic force and damping force develop are orthogonal (i.e. for an axial elastic distortion, the displacement that provides the damping, is radial due to the relative movement between the central and peripherical elastic blade packages).

By the use of an elastic blade package to take over the loads, the contact pressure between two surfaces which are in a relative movement, is small and blocking phenomena cannot occur because the elastic packages are deflecting in a controlled manner according to the loads, without generating some local overstress and overlapping that might "jam" the sliding.

The experimental data obtained with the two models show that by the use of the new types of SECAF support, the following advantages are obtained:

- the balance of forces established in the pipe network and supports is smaller than with the classic supports due to the fact that they take over the permanent loads with a pre - set elasticity, allow the displacements from thermal expansion of the pipes with very low reaction forces and also damp the shocks and vibrations generated by the fluid circulation through the pipe networks and the operation of the equipment under all operation requires (i.e. from cold pipe to maxim temperature regime);
- loads in pipe networks generated by seismic events are reduced up to 3 times due to the enhance of damping in the supports and the effect of isolation produced by the supports as to the supporting structure;
- the installation and modelling errors have smaller effects on the pipe network load condition because the attachement of supports to the pipes and the supporting structure and the their operation procedure are adequate and easy to control (i.e. no blockings and the loads are taken over by the elastic blade package connected in paralel so that the contact pressure is much reduced and blockings are avoided);
- the life - span of the pipe networks installed on SECAF supports is expected to be longer due to the fact that the amplitude of the static (thermal) and dynamic (vibrations, shocks) load cycles, is getting much smaller;
- displacements with a pre-set friction force of about ±90 mm and without an elastic reaction as well as displacements of ±36 mm with a pre-set elastic reaction force, can be obtained by the installation in series of several elastic blade packages so that to make-up a compact assambly of small size (upon request, SECAF supports may be manufactured for any imposed displacement with / without elastic reaction force);
- installation of supports in the existing or new pipe networks or power equipment leads to a several times reduction of the amplitude of the vibrations generated by the operation regime and the seismic movements actually conceal the loads from thermal expansions.

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