Wire Rope Isolators For Seismic Base Isolation

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INTRODUCTION

Electric substations are part of the electric grid system that ensures the delivery of safe and reliable power to every day consumers. Substations transform voltage from high to low or the reverse. A substation may include transformers, surge arresters, circuit breakers, etc.

Some substation equipment are extremely vulnerable to seismic excitations due to their tall and slender design. The failure of such equipment following an earthquake can lead to devastating consequences, which must be avoided at all costs. The IEEE Std 693-2005 serves as a design guideline to improve the seismic vulnerability of such substation equipment installed in seismic areas.

One of the most economical ways to increase the seismic resistance of substation equipment is through base isolation. There are numerous base isolation technologies currently in use such as the triple pendulum bearing, ring friction springs, and wire rope isolators. A case study using the latter isolation technology will be discussed throughout this report.

BACKGROUND

Some electric substation equipment such as surge arresters are extremely vulnerable to seismic events. There are three reasons to their vulnerability:

1. Design: Surge arresters are tall and slender equipment which causes them to have very low bending modes (about 2 Hz), which puts them in the amplification region of the spectral acceleration response to a seismic input, as shown in Figure 1. The amplification region is from 1 Hz to 8 Hz, where the input of the seismic signal is the most amplified.

2. Material: Surge arresters are made of porcelain due to its high insulation characteristics. Porcelain is a fragile and brittle material, which makes its poorly resistant to seismic excitations.

3. Damping: Surge arresters exhibit very low material damping (about 2% damping ratio). As seen from Figure 3, an equipment with larger damping will have a significantly reduced acceleration response due to seismic excitations.

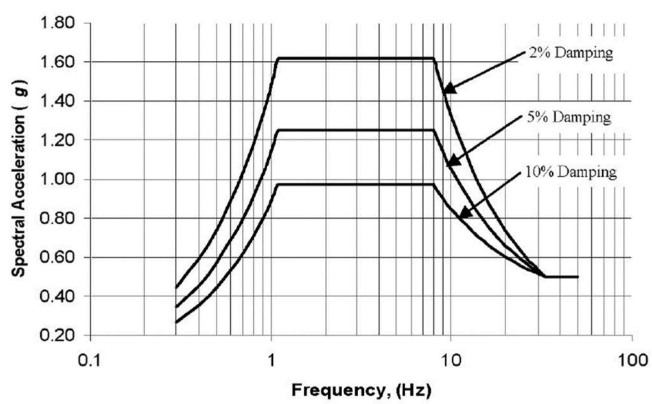

Figure 1. Spectral Acceleration of a 0.5g peak ground acceleration seismic input.

There are numerous ways to improve the seismic vulnerability of a substation equipment. A common solution is to stiffen the equipment so that its natural frequency is beyond 10 Hz and is no longer in the amplification region of a seismic input. This is often not practical and extremely costly. Another way to improve the seismic vulnerability of a substation equipment is by changing its porcelain material to either a stronger porcelain or a composite material. This is often used as a solution, but in some cases it can be relatively expensive. One other way to protect a substation equipment from earthquakes is through base isolation. A base isolation solution consists of elastic mounts that provide elasticity to reduce the high stresses at attachment points, and additional damping to reduce the acceleration response of the equipment. Base isolation solutions are in some cases the most economical way to improve the seismic vulnerability of substations equipment.

There are numerous base isolation technologies used in the market, and wire rope isolators (WRIs) based systems have recently proved to be a very effective base isolation solution. WRIs exhibit high damping through the friction between the strands of the wire rope that is equivalent to around 20% damping ratio. In addition to that, by design WRIs have large dynamic deflection capabilities in all axis enabling them to absorb much of the seismic energy without bottoming out. Other advantages to WRIs are they possess a long lifetime which will outlast the equipment they support, require no maintenance, and perform under a wide temperature range.

CASE STUDY

The Socitec Group was contracted by a substation equipment manufacturer to design a base isolation solution for their high voltage surge arrester. The surge arrester's data was given by the customer:

- The natural frequency of the surge arrester is 3.1 Hz.
- The natural frequency of the surge arrester + the pedestal hard mounted to the foundation is 2.5 Hz.
- The damping in the arrester + pedestal system is 2% viscous damping ratio.
- The ultimate bending moment of the porcelain is 96 kN-m

The goal is to provide a solution resulting in a bending moment less than 96 kN-m under a 1g peak ground acceleration input.

a) *Modeling the chimney*

To model the dynamics of the chimney, the Socitec Group used its proprietary simulation software, SYMOS. It is a nonlinear, multiple degree of freedom software package using the lumped element method to calculate the response of a system. In SYMOS each body is assumed rigid, and the interactions between the bodies are incorporated using links that can be nonlinear.

The simulation models, shown in Figure 2, were comprised of 7 rigid bodies for the hard mounted case, and 9 rigid bodies for the elastically mounted case. Each rigid body has six degrees of freedom (DOFs), which means that the hard mounted case has 42 DOFs and the elastically mounted case has 54 DOFs. SYMOS uses the geometries and density of each body to calculate its dynamic properties (mass, CG location, moments and products of inertia). Since SYMOS considers the bodies to be non-deforming (i.e. rigid), it uses elastic links to simulate the flexibility and damping of the connections between the bodies as well as the flexibility of the bodies themselves.

1) Description of the model for the hard mounted case

- The ground (S1) was modelled with a large enough seismic mass, so that it is uncoupled with the response of the pedestal and the arrester. The seismic input was applied to (S1).
- The pedestal was modelled as one body (S2). The geometries of the pedestal were adjusted to match the information provided to us in the drawings. With these, SYMOS calculates the dynamic properties of the pedestal. The pedestal is attached to the ground (S1) by four links, which are used to model the flexibility of this connection and of the pedestal. The stiffness of the links was tuned to a value such that the pedestal + arrester exhibit a first bending mode at 2.5 Hz, as per the information supplied to us.
- The first column of the arrester and the base mounting kit were modelled as one body (S3). The geometry of this body was mainly composed of a cylindrical shell, which was used to get its dynamic properties using SYMOS. The body is attached to the pedestal below it by one link which models the stiffness of this connection and of the body (S3). The damping of (S3) was assumed to be 2% viscous damping.
- The second column of the arrester (S4) was modelled exactly the same as the first column (S3) but without the base mounting kit mass. Just like (S3), one link was used to model the stiffness of the connection between (S3) and (S4) and the stiffness of (S4) itself.
- The third column of the arrester was modelled as a single body (S5). S5 is attached to S4 by one link to model the stiffness of this connection and its own stiffness.
- The fourth column of the arrester was modelled as a single body as well (S6). The body is attached to (S5) by one link to model the stiffness of this connection and its own stiffness.
- The HV-terminal and the corona/grading rings were modelled as a single body (S7). The connection between S6 and S7 was assumed quasi-rigid using one link.

  Note the five links used to model the stiffness of the entire arrester, were tuned in order to achieve the 3.1 Hz first bending mode of the arrester alone. In fact it was the rotational stiffness of these links that had to be tuned to achieve this 3.1 Hz natural frequency.

2) Description of the model for the elastically mounted case

The elastically mounted case was modelled the same way as the hard mounted case, except for the portion just above the pedestal, where the wire rope isolators (WRIs) are located. In order to connect the WRIs to the top of the pedestal a lower steel plate (S8) is used, and to connect the WRIs to the base of the arrester an upper steel plate (S9) is used. Figure 5 shows the design of the plates and how the WRIs are mounted between the lower and upper plates.

- The lower steel plate is attached to the pedestal (S2) using one link. This link has a very large stiffness, assuming the connection from the lower plate to the pedestal to be quasi-rigid.
- The upper steel plate is attached to the lower plate (S8) by six WRIs. These WRIs have nonlinear stiffness and damping, which are used to simulate the behaviour of the WRIs in reality. The data of the WRI stiffness and damping comes from numerous tests done over the years. Many different WRIs were investigated in this study, and the chosen WRI was the one that showed the largest reduction in the moment at the base of the arrester, while not allowing too much motion at its top.

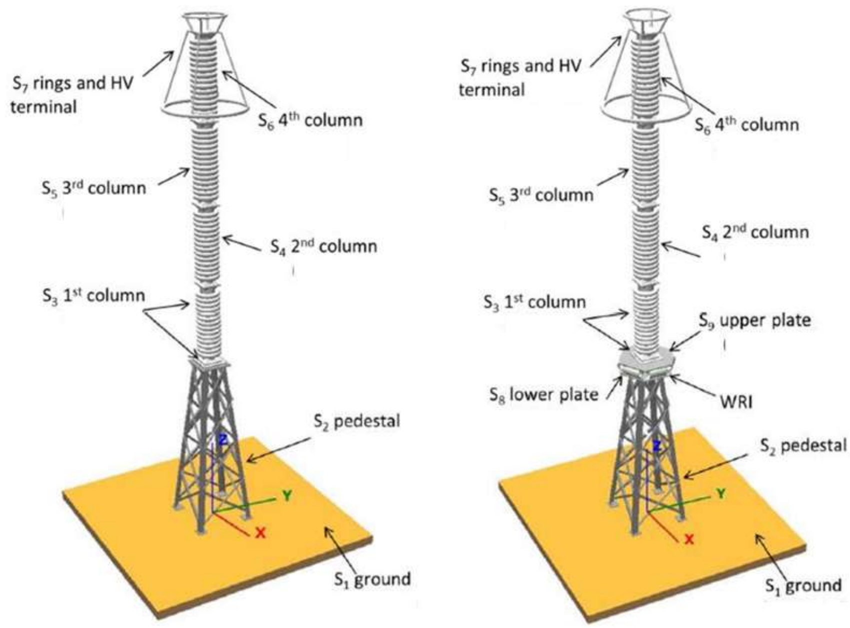

Figure 2. Models used for the transient dynamic study: hard mounted (left), elastically mounted (right).

Figure 3. The Socitec Group's WRI Assembly Solution.

b) <u>Input Applied to the Model</u>

The applied time history seismic input was compliant with all IEEE Std 693 requirements. That is, the seismic time history inputs had a response spectrum that enveloped the 1g RRS (with 2% damping) in the two perpendicular horizontal axes, and in the vertical axis (80% of the horizontal axes). The seismic input also had more than 20 seconds of strong motion, and its strong part ratio was above 30% as required per the IEEE Std 963. The seismic time history input and its corresponding response spectrum in the X-direction are shown as an example in Figures 6 and 7. Note that numerous seismic input orientations were considered in this study and the one providing the worst case response is the one shown in this report.

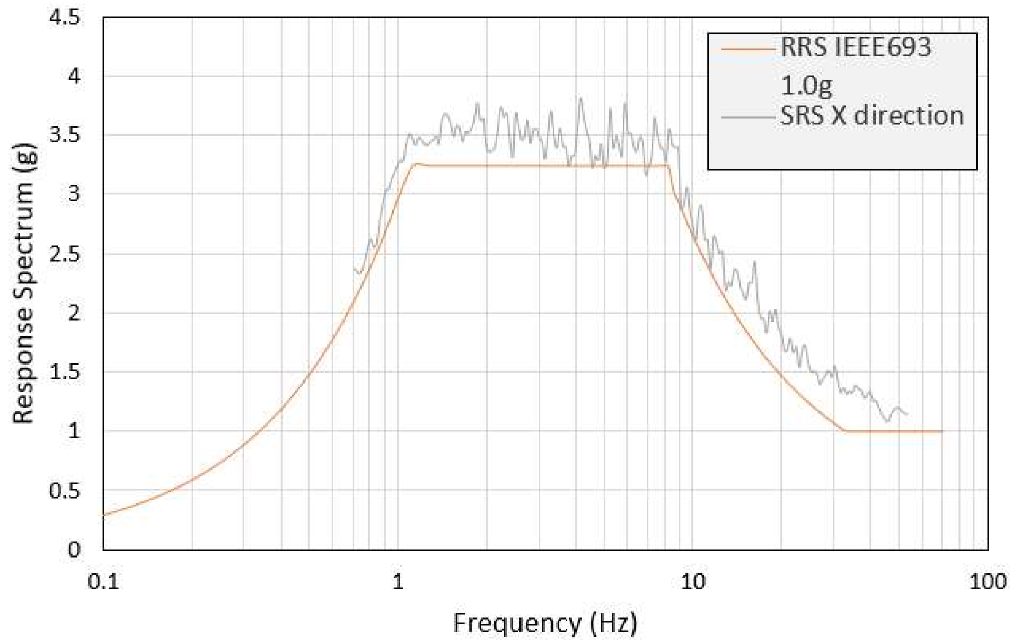

Figure 4. Shock Response Spectrum of 1g time history input in X-direction

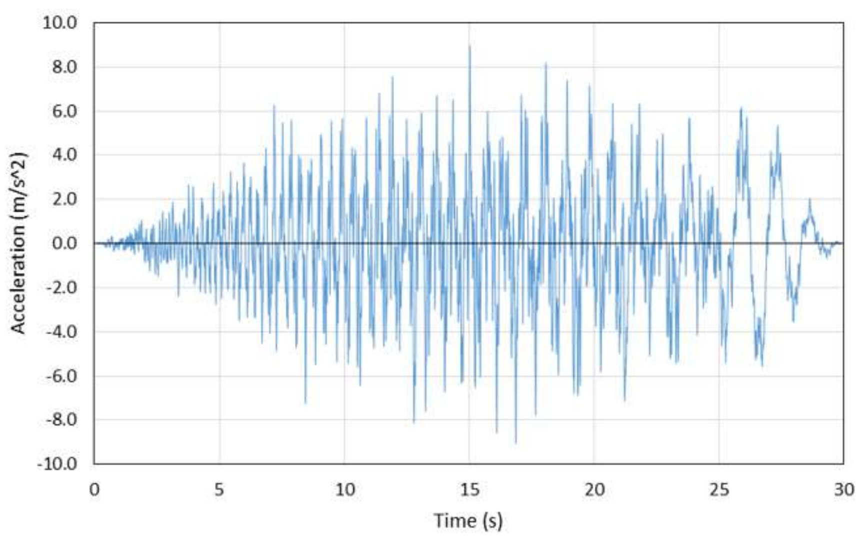

Figure 5. 1g time history input in X-direction

c) Results and Conclusions

A time history nonlinear analysis was accomplished to calculate the response of the equipment. The study calculated the bending moment at the base of the arrester, the displacement at the top of the arrester, and the deflections in the WRIs. The latter one was calculated to ensure that the chosen WRIs are deflecting within their capacities in response to the inputs.

The results from the 1g tri-axial input showed that when the arrester was hard mounted using fasteners, the maximum bending moment it experienced was about 160,000 N-m. This is to be compared with the maximum bending moment of 70,000 N-m, when the arrester was mounted on six WRIs. This represents more than 55% reduction in the bending moment experienced in the arrester by using WRIs. Given that the ultimate bending strength of the porcelain is 96,000 N-m, this means that the arrester will survive the 1g performance level when mounted above the WRIs. The results are shown in Figures 6-9.

The results also showed that the deflections of the isolators are well within their capabilities, even under repeated long term forces, so no fatigue problems are to be expected.

This solution was tested on a shake table and approved per the IEEE Std 693-2005. Test results were very close to the simulation results. The pictures of the test setup for the hard mounted and the elastically mounted cases are shown in Figure 10.

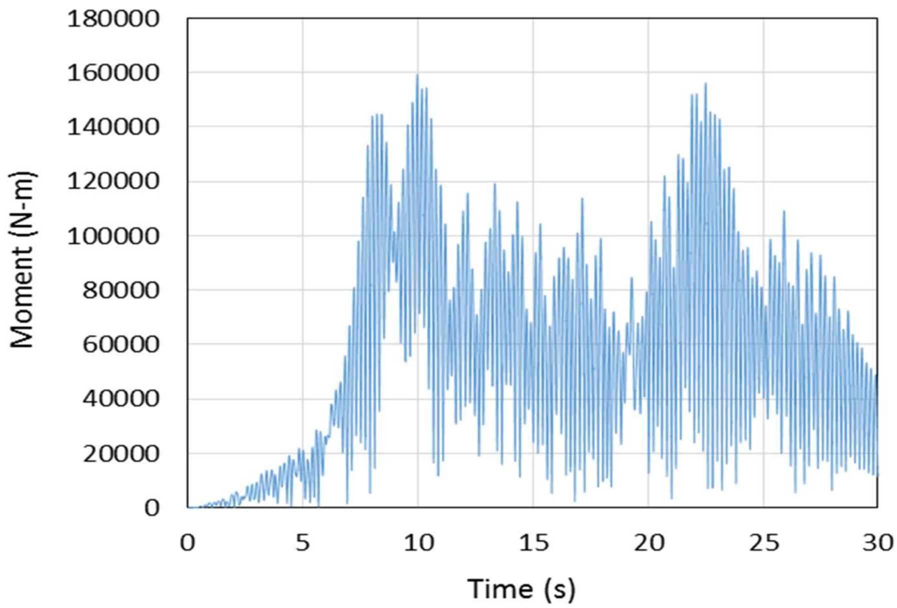

Figure 6. Resultant bending moment* at the base of the arrester for the hard mounted case.

$$^{*}M_{resultant} = \sqrt{M_x^2 + M_y^2}$$

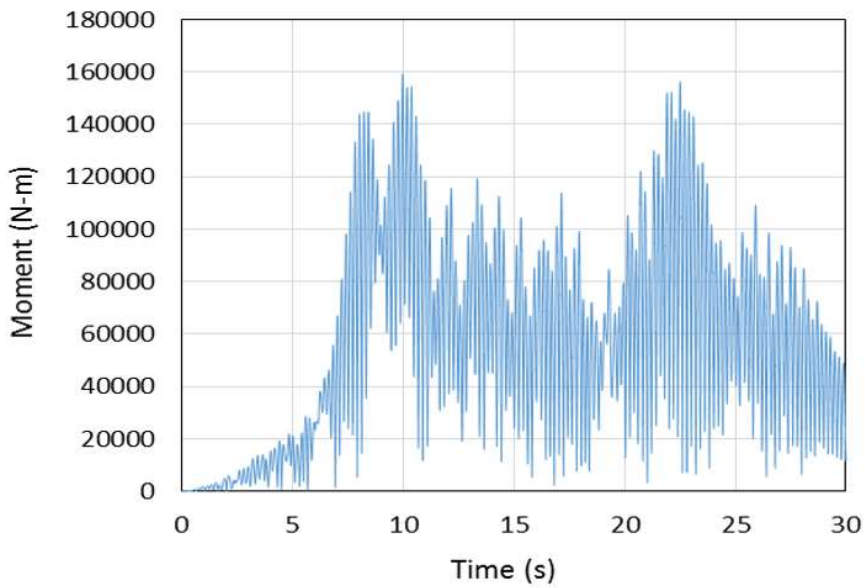

Figure 7. Resultant bending moment at the base of the arrester for the elastically mounted case.

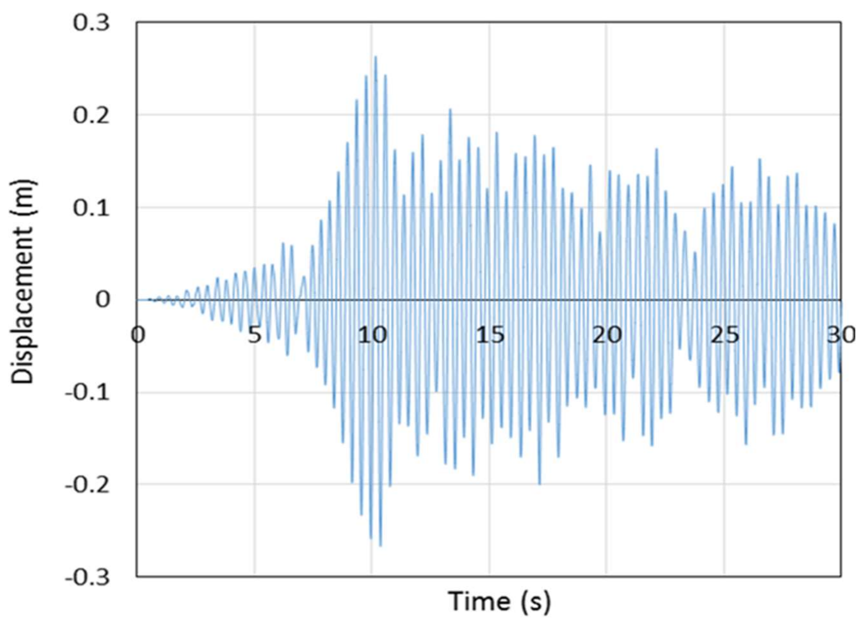

Figure 8. X-direction displacement of the top of the arrester for the hard mounted case.

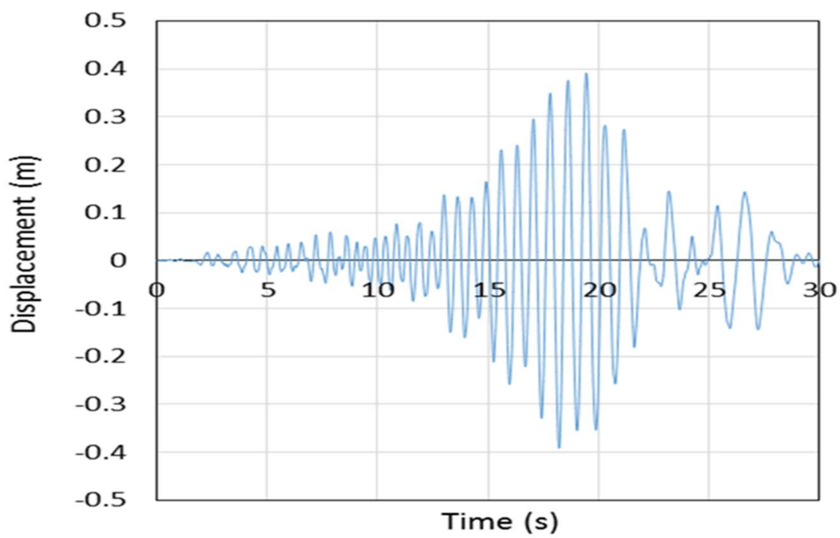

Figure 9. X-direction displacement of the top of the arrester for the elastically mounted case.

Figure 10. Test setups used of hard mounted case (left), elastically mounted case (right).

FUTURE PROJECTS AND DEVELOPMENTS

The Socitec Group is currently working on a solution to support an entire substation using its newly developed 2 inches diameter cable. The idea is instead of supporting each substation equipment individually, high bearing capacity WRIs can support an entire substation instead.

The Socitec Group has also just developed a new high damping cable achieving twice more damping than the standard cable, as shown in Figure 11. This new high damping cable can achieve up to 35% equivalent viscous damping ratio. As was explained in this report, high damping provides a strong advantage in seismic applications.

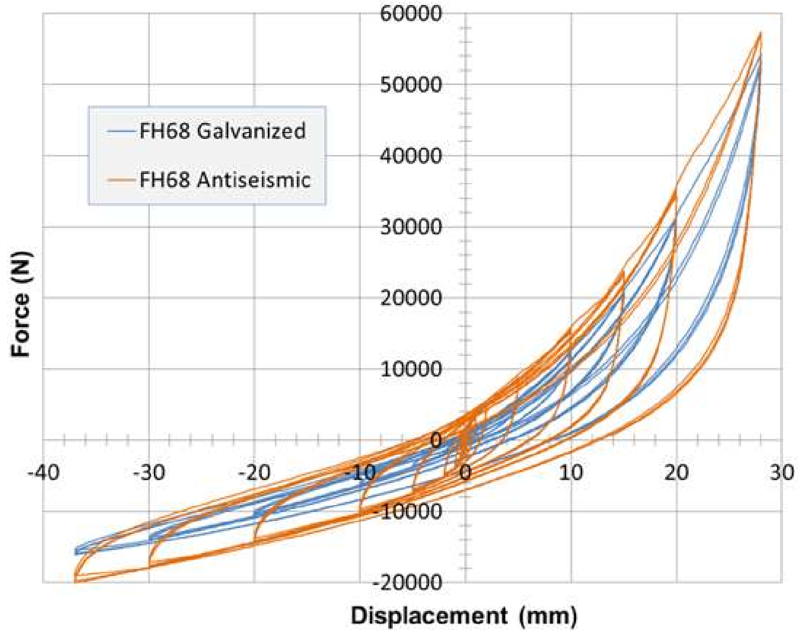

Figure 11. Damping comparison between galvanized cable and newly developed high damping cable.