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Seismic tests of high voltage equipment in Argentine

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ABSTRACT: This report describes the testing facility, the methodology applied and the results obtained in the seismic qualification tests of two 500 KV measurement transformers performed on the shaking table mounted at the Earthquake Research Institute of the National University of San Juan, Argentine.

The testing facility consists of a shaking table the driver of which is a hydraulic jack electronically controlled by a computer, and a multichannel data acquisition system based on PC computer. Both were developed and built at our Institute.

The two of the 500 KV measurement transfomers tested consist of a top chamber assembly, a cylindrical hollow porcelain insulator and the base assembly. To perform the seismic qualification test, each of the transformers was mounted on the shaking table with its steel tower support rising to a total height of 10.5 m.

The electric equipment tested withstood without damage the dynamic stresses generated by the excitation motion required by the owner, with an acceleration response spectrum of 0.4 g for their dynamic characteristics.

1 INTRODUCTION

Earthquakes have often affected the electric power systems of important areas causing the interruption of power supply to industries and homes, which sometimes has extended during days.

In the electric power systems, some components of high voltage substations have shown to be very sensitive to the shaking of strong earthquakes. Thus, measurement transformers, disconnecting switches, circuit breakers and other similar substation equipment of 220 KV or larger voltage have been severely damaged on the 1978 Miyagi-Oki, Japan earthquake (Katayama 1980), on the 1987 Bay of Plenty, New Zealand earthquake (Rutledge 1988) and on the 1989 Loma Prieta, USA earthquake (EERI 1990).

The restoration of the operation of this equipment at these substations demands time which produces important economic losses that are larger than the reposition cost itself. For this reason, it is neccesary to give, in the design and construction stages, a special attention to the future seismic behavior of the electric equipment of high voltage substations.

Because of its very special features, it is convenient to verify the seismic aptitude of this equipment not only by means of appropriate numerical analysis of mathematical models and mechanical test of materials, but also by performing seismic qualification

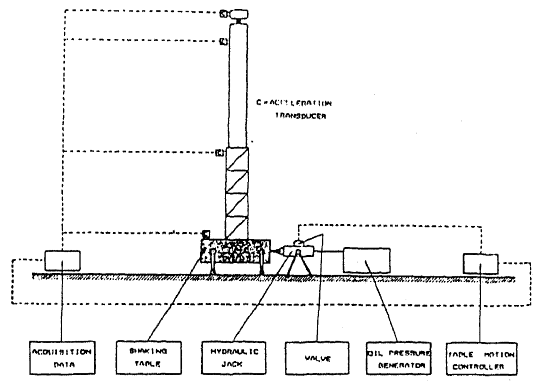

Figure 1. Shaking Table Scheme.

tests in which the motion of the equipment during the earthquake is simulated. Their weights allow the qualification test to be performed on the shaking table, the equipment being mounted in a condition similar to that at the substations.

With the purpose of carrying out dynamic tests on full scale substation electric equipment subjected to seismic motion, the Earthquake Research Institute of the National University of San Juan, Argentine, has designed, built and put into operation one shaking table. With this testing facility the seismic qualification tests of two 500

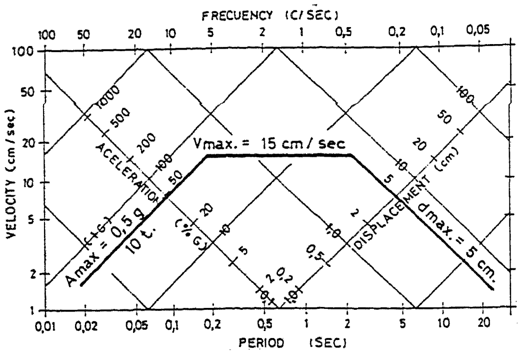

Figure 2. Shaking Table Operation Limits.

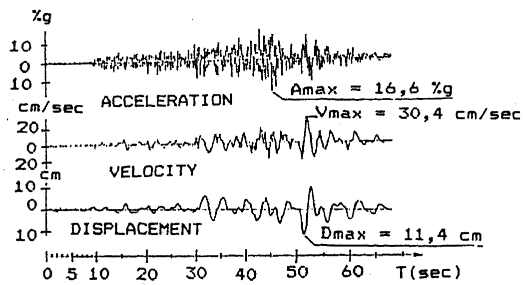

Figure 3. Acceleration Record of San Juan, Argentine, Nov 23, 1977, earthquake.

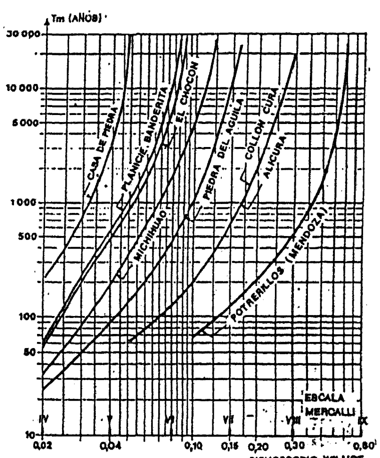

Figure 4. Mean Return Periods of Seismic Intensities in Limay River Area Locations.

KV measurement transformers have been recently performed. These belong to a set to be installed in substations located in a seismic area of Argentine with a medium intensity level. The principal features of the shaking table, the methodology applied during the tests and the equipment behavior are described in this report.

2 THE SHAKING TABLE

The shaking table mentioned above has only one horizontal degree of freedom and has been designed and built keeeping in mind that the electric equipment of high voltage substations to be tested are slender and that they have normally the centre of gravity in such a position as to generate a very important seismic overturning moment at the base of its supporting frame. The testing facility is located in San Juan City which, with its mild and very dry climate, allowed the facility to be built outdoors. This fact also simplifies the erection of the equipment to be tested which has a total height a little larger than 10 meters. The frame and supporting elements of the shaking table are metalic, conforming a unit stiff enough so that the fundamental natural period in the slenderest equipment to be tested will not be modified by an amount larger than 1,5%.

The horizontal and monoaxial motion of the shaking table is driven by a bidirectional hydraulic jack whose action is regulated by a valve the position of which is commanded by means of an electric signal sended by one PC through an appropriate interface. In the computer, instant to instant, the control algorithm compares the real and the required *cinematic values of the shaking table motion* and emits the electric signal to maintain or to correct the valve position in order to obtain the desired motion on the shaking table by means of the hydraulic jack, Figure 1 The operation limits corresponding to this testing facility are shown in Figure 2.

The installation has also the data acquisition system to measure and record the cinematic variables which correspond to motions both of the shaking table and the equipment under testing. It includes acceleration and displacement transducers, their electronic amplifiers and filters and the interface to introduce the information in a second PC which has the necessary software to record it, to graphically present the motions immediatly and also to perform their further analysis.

The whole installation has been designed by the authors of this report, including the frame and supports of the table, the transducers and electronic circuits of the data system and its software. The authors also have supervised its construction and the data acquisition system has been assembled at our Institute.

3 SEISMIC QUALIFICATION TEST MOTIONS

The electric equipment seismic qualification tests are the experimental approach to demonstrate the ability of the equipment to perform its required functions during and after the occurrence of earthquakes. Consequently, it is necessary to select the characteristics of the shaking table motions that will be applied during the tests. They are related to the seismic intensity levels which are expected to occur at the site where the electric equipment will be operated.

About the seismic activity in Argentine, the most destructive earthquakes have occurred at the centre of the western part of its territory, (Volponi 1962). For example, in november 23, 1977 the city of San Juan was shaken with Mercalli Intensity VIII by one Ms = 7,4 earthquake from an epicentral area at a distance of 60 km. Figure 3 shows the acceleration record obtained in San Juan city on that occasion with a maximum acceleration 0,17g whereas one Wilmot seismoscope with a period 0,7 sec and 10% of damping located on the same site recorded 0,26g as spectral acceleration. (Carmona 1978).

The two 500 KV measurement transformers tested will be installed in substations of Hidronor's hydroelectric power plants located at Limay River in Comahue Region, one thousand km. to the south of San Juan City, where the seismic activity is lesser than in this place. The Limay River seismic risk studies (Carmona 1988) Figure 4, estimated a value of 0,14 g for spectral acceleration of the Wilmot seismoscope on rock site with a five hundred years mean return period, whereas this value is 0,30 g for San Juan.

To seismically qualify the substation electric equipment Hidronor, the owner, specified the spectral response acceleration curve shown in Figure 5 with a maximum value of 0,26 g. The shaking table motion to fulfil this requirement was specified to be of the sine-beat type acceleration, in accordance with other specifications.(IEEE 1975), (IEC-50A 1983). The specified acceleration requires a sequence of 5 sine-beats separated by quietness intervals, each sine-beat having five complete sine waves with their amplitudes modulated by a semi-senoidal wave and their periods are equal to the fundamental natural period which has the equipment under testing in the direction of the shaking table applied motion. Figure 6 shows one acceleration sine beat and its corresponding displacement time curve in which a residual value occurs. The amplitude of each sine-beat acceleration must be such that the tested equipment response acceleration will be equal or larger than the spectrum curve of Figure 5.

4 - PERFORMED TESTS

The two of the 500 KV measurement transfomers tested consist of a top chamber assembly, a cylindrical hollow porcelain insulator which houses the primary and secondary windings, and the base assembly.

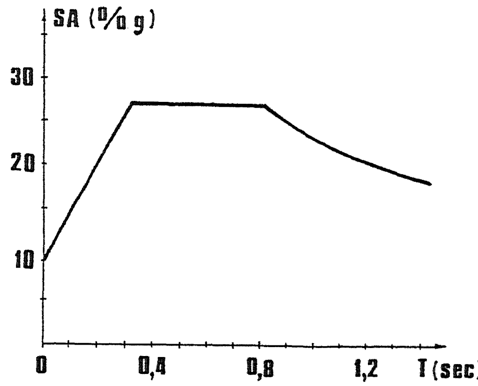

Figure 5. Acceleration response spectrum required by Hidronor.

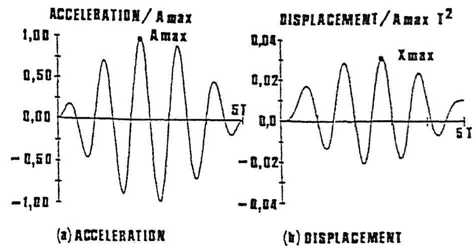

Figure 6. Sine-beat type acceleration of shaking table motion required by Hidronor.

One of them, an AOK 525 MC current transformer was 6,5 meters in height whereas the other, a WE 550 F/S voltage transformer was 5,3 meters high both constituting slender elements. To perform the seismic qualification test, each of the transformers was mounted on the shaking table with its bolted steel tower support rising to a total height of 10,5 m., thus increasing its slenderness. It is very important to properly reproduce the service condition on the substations since the tower support changes the dynamic characteristics of the transformer, a change that was taken into account in the shaking table process design. Figures 7 and 8 show each one of the electric devices tested erected over the shaking table. These are units of a set of two hundred of them manufacturated under licence by Tubos Trans Electric in its plant at Córdoba, Argentine, and which will be located by Hidronor in their 500 KV Electric Power Transmission Systems substations.

Prior to the shaking table tests and in order to know about natural periods and damping, in-situ vibration studies in other units of equal type installed in Choele Choel substation of 500 KV Alicurá Electric Power Transmision System of Hidronor have been made. With that purpose, by means of

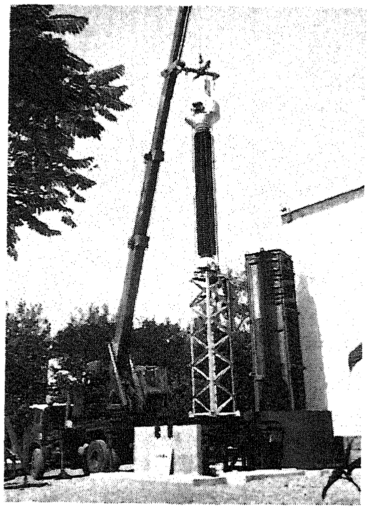

Figure 7. 500 KV Current Transformer erected over the shaking table for testing.

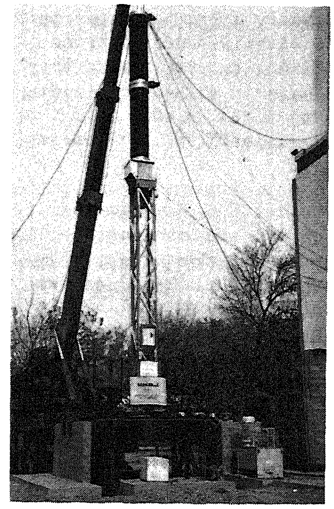

Figure 8. 500 KV Voltage Transformer erected over the shaking table for testing.

seismic type instrumentation the micro - vibrations generated by the wind and ambiental excitation on significant points of the selected measurement transformers were recorded. In Figure 9 one of these records obtained in the 500 KV current transformer is shown. By Fourier Transform calculation the fundamental natural frequency of 1,40 hertz has been detected and from the amplitudes decreasing analysis about 2% damping has been estimated. The microvibration amplitudes are very low when they are compared with that generated by earthquakes, but they give a valuable information to perform the shaking table tests.

After the transformer erection on the shaking table, the instrumentation to measure and record the cinematic variables during the tests was installed. It includes 6 accelerometer transducers distributed along the height of the electric device under testing and 2 strain gauges cemented on the base of its porcelain insulator, all of them connected to the data acquisition system in which the information was measured and recorded as digital data at a sampling of 200 times per second in each channel. In like manner, the excitation motion acceleration at the shaking table was registered by the data acquisition system.

The tests carried out on the shaking table have had two stages: the identification of transformer dynamics parameters and the shaking produced by the required motions. In the first stage one sloped step and sinusoidal scanning motions of the shaking table were applied in order to determine the natural periods, mode shapes and damping of the electric device under testing. Their response amplitudes were lesser than one-third of

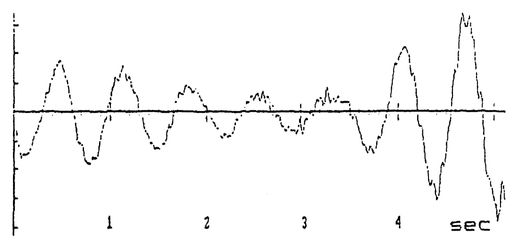

Figure 9. Wind excited microvibration of 500 KV Current Transformer recorded on Choele Choel Hidronor substation.

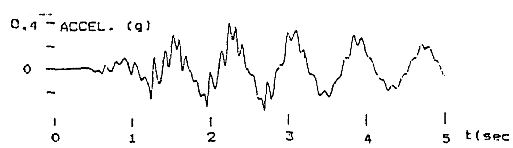

Figure 10. Acceleration-time curve measured on the upper part of the 500 KV Current Transformer during the shaking table test.

that corresponding to the earthquake required motions. In the current transformer test frequencies of 1,35 and 1,30 hertz were found for the fundamental modes for two different horizontal directions whereas in the voltage transformer test these frequencies were 1,6 and 2,0 hertz. In both tests the damping values found were between 2,5 and 3% of critical.

After the identification of the dynamic parameters the required motions for the equipment qualification were applied. These shaking table motions were of the sine-beat

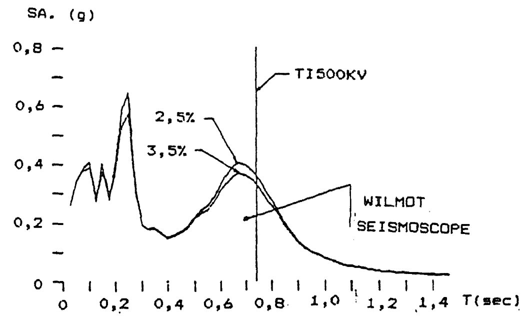

Figure 11. Acceleration response spectrum of Figure 10 acceleration time curve.

type in Figure 6 with amplitudes successively increased until the response acceleration of the equipment tested was equal or larger than that specified on Figure 5, which was 0,26g for both transformers as a consequence of their natural frequencies. In the current transformer the maximun response spectral acceleration obtained during the test was 0,30g whereas in the voltage transformer it was 0,38g, both larger than the required value given in Figure 5. Figure 10 shows the acceleration-time curve measured in the upper part of the current transformer during one of the strongest sine-beat shaking table motions, whereas in Figure 11 the 2,5 and 3% damping acceleration response spectrum curves of the motion applied are shown.

In Figure 11 the value 0,21 g corresponding to the Wilmot seismoscope is also shown. This is something lesser than the value 0,26g recorded in San Juan during the november 23, 1977 earthquake mentioned above, but enough for the medium intensity seismic area where these electric devices will be installed. Moreover, this 0,21g seismoscope value shows that the transformer under testing felt the shaking table motion in a way similar to one earthquake between VII and VIII Mercalli seismic intensity.

Finally, it must be pointed out that after the shake neither through visual inspection nor through electric measure tests any disturbances or damage on the measurement transformers tested have been detected. In this way, the seismic qualification test of these electric devices to be installed on the substations of Hidronor 500 KV electric power system, has been successfully completed.

5 FINAL REMARKS

It should be pointed out that the testing facility built is at present the largest one of its type in Argentine and the equipment tested is the highest, heaviest and slenderest one which has been seismically qualified on a shaking table in this country.

The authors would like to thank both Tubos Trans Electric, the manufacturer, and Hidronor, the owner, in particular Mr. E. Rimondi from the former firm and Mr. G. Pontoriero from the latter for their support which permitted this testing facility to be constructed and the seismic test to be carried out.

Furthermore, even though this shaking table has only one degree of freedom, the tests performed have been a valuable experience for a better understanding of the seismic behavior of special electric devices the complexity of which renders the mathematical models insufficient to study the dynamic properties of these devices. In the near future other degrees of freedom will be added to this testing facility in order to be able to better represent earthquake motions.

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