# Monitoring of the Hill and the Circuit Wall of the Athenian Acropolis Utilizing Optical Fibre Sensors and Accelerographs

Dr. Elena Kapogianni[1], Dr. Kalogeras Ioannis[2] and Dr. Prodromos Psarropoulos[3]

[1] National Technical University of Athens, Greece

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## Abstract

The Acropolis of Athens is one of the most prestigious ancient monuments in the world, attracting daily many visitors, and therefore its structural integrity is of paramount importance. During the last decade an accelerographic array has been installed at the Archaeological Site, in order to monitor the seismic response of the Acropolis Hill and the dynamic behaviour of the monuments (including the Circuit Wall), while several optical fibre sensors have been attached at a middle-vertical section of the Wall. In this study, indicative real time recordings of strain and acceleration on the Wall and the Hill with the use of optical fibre sensors and accelerographs, respectively, are presented and discussed. The records aim to investigate the static and dynamic behaviour ? distress of the Wall and the Acropolis Hill, taking also into account the prevailing geological conditions. The optical fibre technology, the location of the sensors, as well as the installation methodology applied is also presented. Emphasis is given to the application of real time instrumental monitoring which can be used as a valuable tool to predict potential structural risk.

***Index terms***— accelerographs, ancient monuments, monitoring, potential structural.

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# 1 Introduction

he Acropolis Hill is the most outstanding ancient Greek monumental complex still existing in our time and was chosen due to its geomorphology since the Neolithic period (4000 / 3500-3000 BC) as a place for local residents. It has a height of about 150 m above sea level and 70 m from the level of the city of Athens. Among the standing monuments of the Hill, the Circuit (perimeter) Wall serves a pure geotechnical purpose, since it functions as a typical gravity wall, retaining the backfill that forms the plateau of the Acropolis and has total length of about 800 m and variable height areas 5-20 m. In Figure 1, a panoramic view of the Acropolis Hill from the south-east is depicted. The historical significance of the Archaeological Site, the complexity of the geomorphological conditions in the region, the vulnerability to natural and man-made hazards as well as the need to resolve practical problems encountered during the restoration works have led to the application of various contemporary technologies on the Acropolis Hill and its monuments over the last years. In this framework, multi-disciplinarily instrumental monitoring (via accelerographs and optical fibre sensors) has been included, serving also the extensive restoration works and aiming to real time data gathering for immediate intervention when needed (Sakellariou et al, 2016;Kalogeras et al, 2012).

# 2 II. Geology of the Hill and the Perimeter Wall

The Acropolis Hill is geologically composed mainly by limestone overlying the Athenian Schist (Koukis et al., 2015). The Athenian Schist is visible on the main entrance of the archaeological site and less in other positions while the limestone is visible on the hill, when is not covered by artificial embankments, which have been built in order to create the surface level of the hill. The embankments are thicker on the south side and held around the Wall and the limestone karstification has leaded to cavities which facilitate the water flow, further erosion and rock fall phenomena. Figure 2 shows a geological plan view of the Acropolis Hill (Higgins & Higgins, 1996). The importance of the Perimeter Wall is very high since it provides foundation of other monuments of the hill and the passing of time has seen it undergo numerous damages mainly due to the weather conditions and various types of loading, as well as the human intervention, leading to crack creation and therefore increasing the risk of local and/or extensive structural failures (Ambraseys, 2010;Trikkalinos, 1977).

In Figure 3 the central area of the South Wall is noted, which comprises mainly irregular mixed courses made up of ancient marble blocks in second use (spolia) and small stones, added in later repairs. ). The sensors were fixed at predefined positions on the South Wall with the use of stainless steel plates, anchored to the substrate. The critical positions of the optical fibre arrays were defined by analyzing computational models, utilizing the finite element method (Kapogianni et al., 2017) and the area selected for the final installation was near the preexisting accelerometers ACRD and ACRJ (see Figure 4). Connection in series was achieved via in situ splicing, while strain measurements were made possible with the use of the Optical Sensing Interrogator SM 130. In Figure 5 the location of the new measuring equipment is presented.

# 3 Optical Fibre Sensors and Acceleration Recordings

Time stamped non-continuous and real-time continuous strain and temperature optical fibre measurements were recorded at various positions on the South Wall. Since various physical phenomena affect the Acropolis Hill and the Perimeter Wall, such as very high and low temperatures, excessive rainfalls, earthquakes, etc., the optical fibre monitoring infrastructure aims to quantify their influence on the monument. Equation 1 is used in order to derive strain measurements from the correspondent wavelength recordings.( * ) / ? ? ? ? ? ? ? = ? ? ? ? ?**(1)**

where Î?” ? [%] is the strain change; Î?” ? the wavelength change; ? ? is a ratio expressing the strain-wavelength relation and is equal to 1.2 picometer (pm)/?strain for the sensors type that was used for the current study;

? ? . Î?” ? incorporated the wavelength changes due to the temperature variations, where K ? is equal to 11.2 pm/C o for the sensors used and Î?” ? is the temperature variation, measured during the tests (starting value and actualfinal value).

In Figures 6 and 7 characteristic recordings for time-stamped, non-continuous and real-time continuous strain recordings (including temperature) are presented. The results so far indicate that temperature plays an important role on the strain levels on the Wall. Due to lack of a strong seismic event, no notable acceleration recording has been obtained via the optical fibre sensor. In addition, it is noted that information gained from the non-continuous recordings is of different magnitude and pattern compared to the corresponding ones from the real-time records. In order to derive comprehensive conclusions related to the behavior of the Wall, real-time recordings should be gathered and analyzed for a long period of time and at various positions, including various loading events (e.g. seismic). 8d, for sensors attached on four different locations on the South Wall of the Acropolis Hill. In particular, results via sensors on the top, middle and bottom of the Wall are presented, for an approximately 20-hour period of time. It can be noted that strain increases during the morning and noon and decreases during the night, due to the temperature increase and decrease, respectively. In addition, recordings near the vertical middle section of the Wall are higher, compared to the correspondent values near the top and bottom of the Wall. It should be emphasized that remotely real-time monitoring on various locations on the Wall can provide long-term useful conclusions related to its structural behaviour, especially during various loading events such as seismic, restoration works on the Acropolis site and/or extreme weather conditions. It is evident that the recorded ground motion of the small near-field seismic event is characterized by very low peak ground acceleration (PGA) levels, short duration and high frequency content, while on the contrary, the recorded ground motion of the strong farfield seismic event is characterized by higher PGA levels, longer duration and lower frequency content.

Figure 9 shows the elastic response spectra of four recorded ground motions (ACRB, ACRF, ACRG and ACRJ) during the two examined seismic events. Judging from the shape of the spectra, it becomes evident that, apart from the obvious great differences between the two seismic events, the discrepancies between the four records during the far-field earthquake are relatively small, while on the contrary, during the near-field event there is a substantial variability referencing to the installation site characteristics: the instruments located at the north side of the hill (i.e. ACRF and ACRG) exhibit higher PGA levels and higher spectral accelerations. Continuous lines correspond to the far-field event, while dashed lines correspond to the near-field event V.

# 4 Conclusions

Structural health monitoring is a rapidly growing scientific area, applied initially to structures of economic importance, historical significance and high risk of failure. The use of measuring systems aims to the creation of intelligent structures such as bridges, buildings, geotechnical constructions, etc., that are instrumented with sensors and other devices, providing important real time information on various locations, necessary for early detection of failures. Through sensors and devices installation, useful real time information is gathered, necessary for early detection of structural problems, during construction and life cycle, contributing to safety and their optimal management.

The current paper is involved with the structural health monitoring of the Acropolis Archaeological Site, via optical fibre sensors installed on the South Wall and accelerographs located on the Hill, continuously transmitting data from various locations. The results so far indicate that temperature plays an important role on the strain levels on the Wall however, due to lack of a strong seismic event, no notable acceleration recording has been obtained. It can be noted that strain increases during the morning and noon and decreases during the night, due to the temperature increase and decrease respectively. In addition, recordings near the vertical middle section of the Wall are higher, compared to the correspondent ones near the top and bottom of the Wall. Concerning the recorded ground motion via the accelerographs, it is noted that the small near-field seismic event is characterized by very low peak ground acceleration (PGA) levels, short duration and high frequency content, while on the contrary, the recorded ground motion of the strong far-field seismic event is characterized by higher PGA levels, longer duration and lower frequency content.

Concluding, it should be highlighted that remotely real-time monitoring on various locations on the Acropolis Hill can provide long-term useful conclusions related to its structural behaviour, especially during various loading events such as seismic, restoration works on the Acropolis site or/and extreme weather conditions. VI. [1] [2] [3] [4]

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Figure 1: Figure 1 :

[1] Year 2017

[2] Monitoring of the Hill and the Circuit Wall of the Athenian Acropolis Utilizing Optical Fibre Sensors and Accelerographs

[3] Year 2017EMonitoring of the Hill and the Circuit Wall of the Athenian Acropolis Utilizing Optical Fibre Sensors and Accelerographs

[4] Year 2017

3. Attica

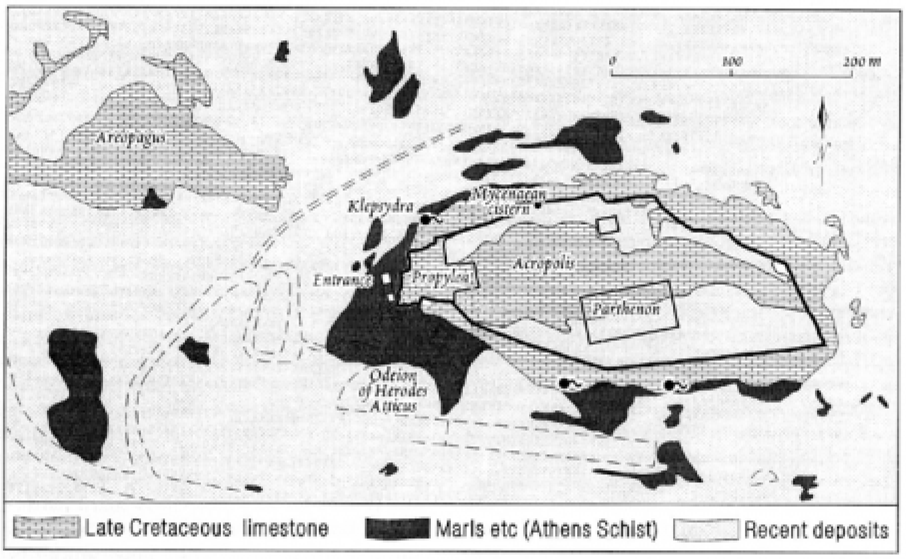


Fig. 3.3. The Acropolis and Areopagus (after 9).

m thick. Much of this deposition occurred during infrequent floods in the recent past.

*The Acropolis*

The Acropolis hill is a block of Late Cretaceous limestone resting on the marls and sandstones of the Athens schist rock series (Figs. 3.3, 3.4), which can be seen on the approach to the main entrance to the site, and just beneath the Propylea.[9, 10, 284] The grey limestone is well exposed on the top of the hill. It has closely spaced joints and some of the older fissures have been filled with red marl or coarse calcite crystals. The top of the Acropolis hill has been levelled with artificial fill up to 14 m thick which is

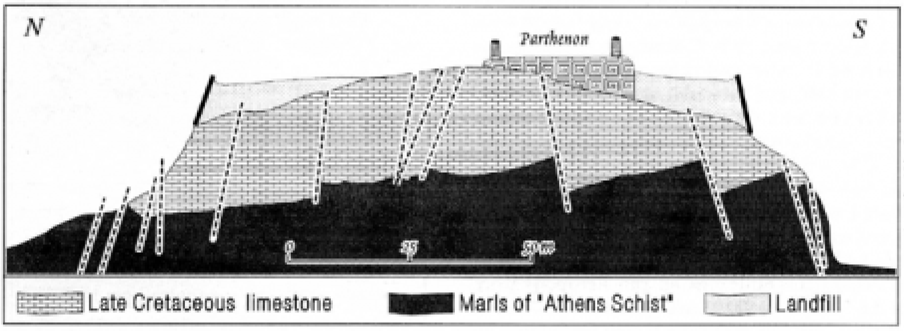


Fig. 3.4. Section through the acropolis (after 9).

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Figure 2: Figure 2 :

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Figure 3: Figure 3 :

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Figure 4: Figure 4 :

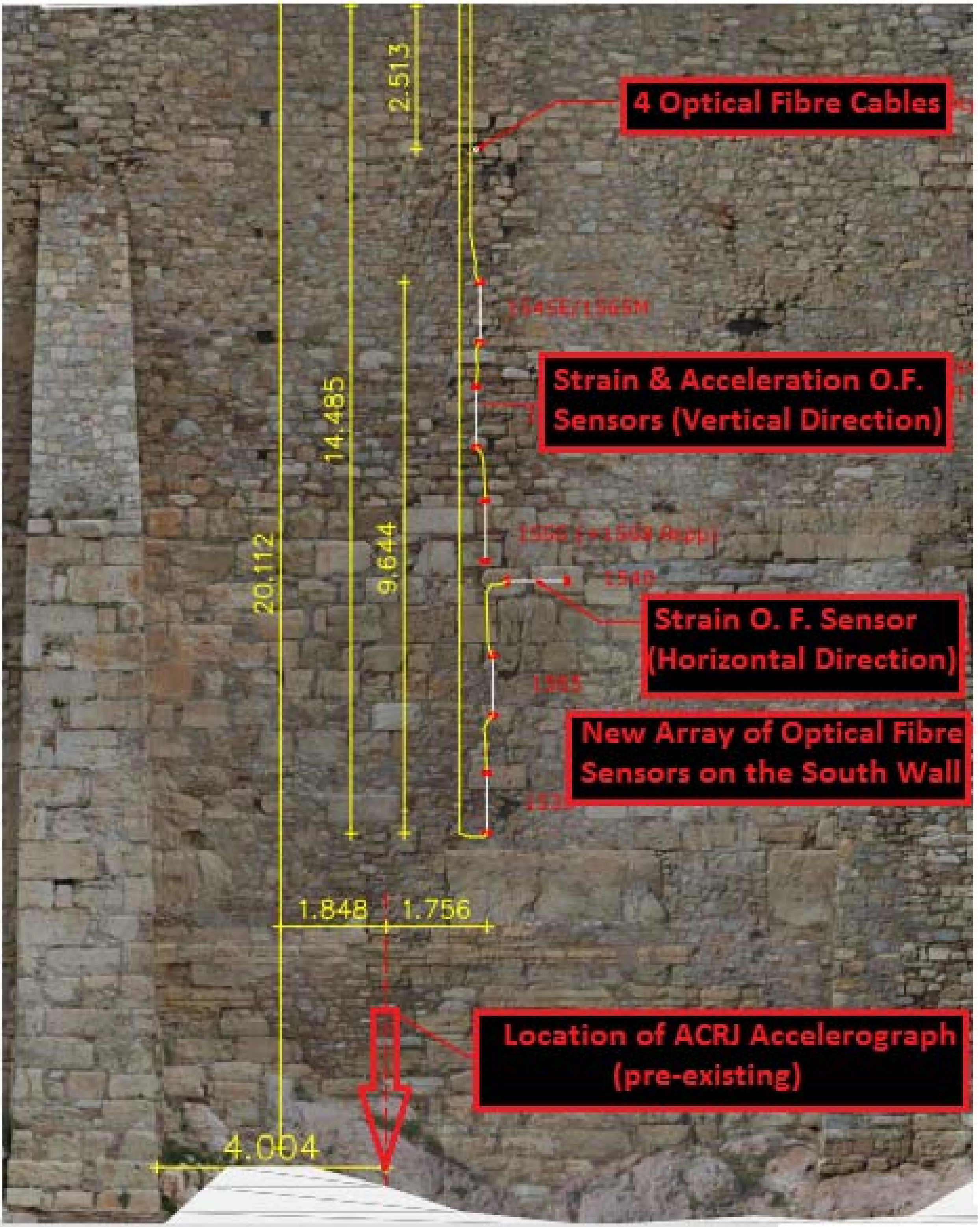


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Figure 5: Figure 5 :

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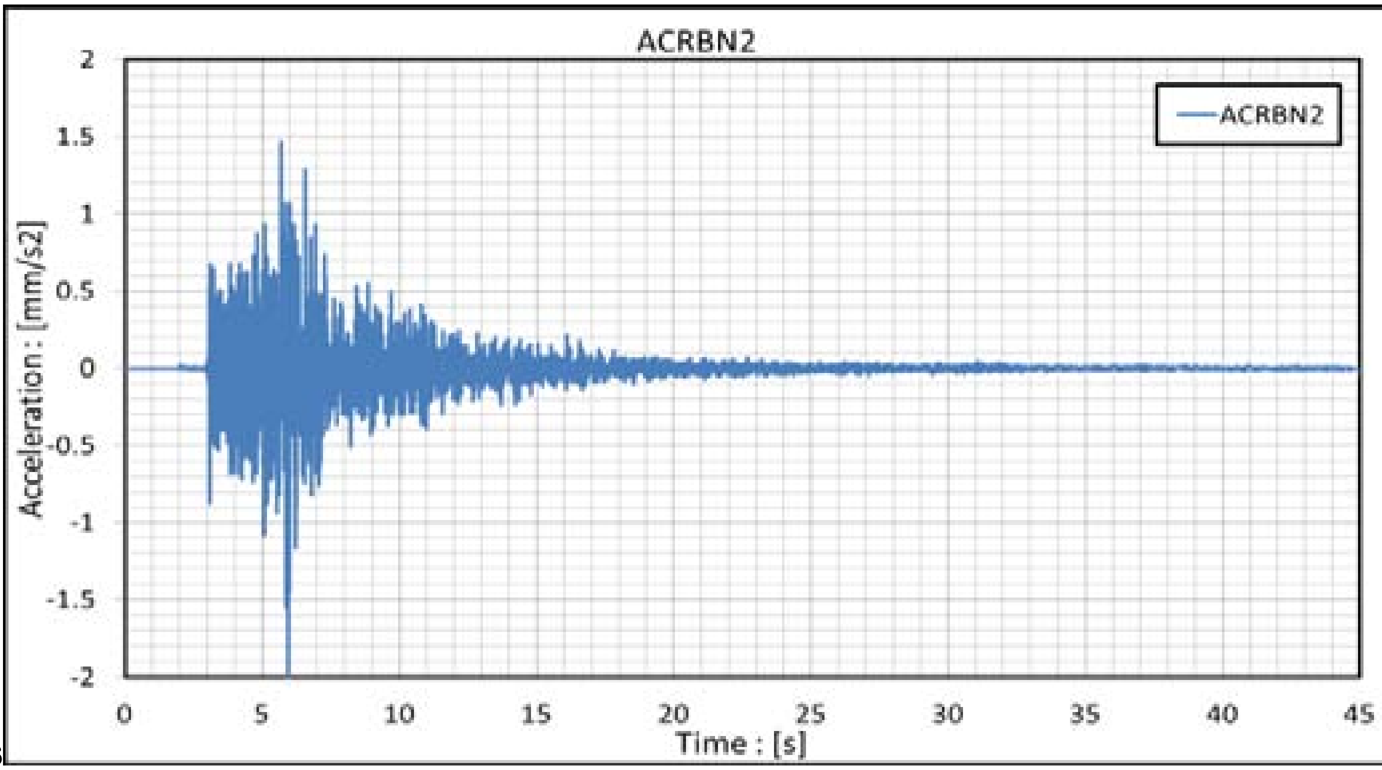


Figure 6: Figure 6 :

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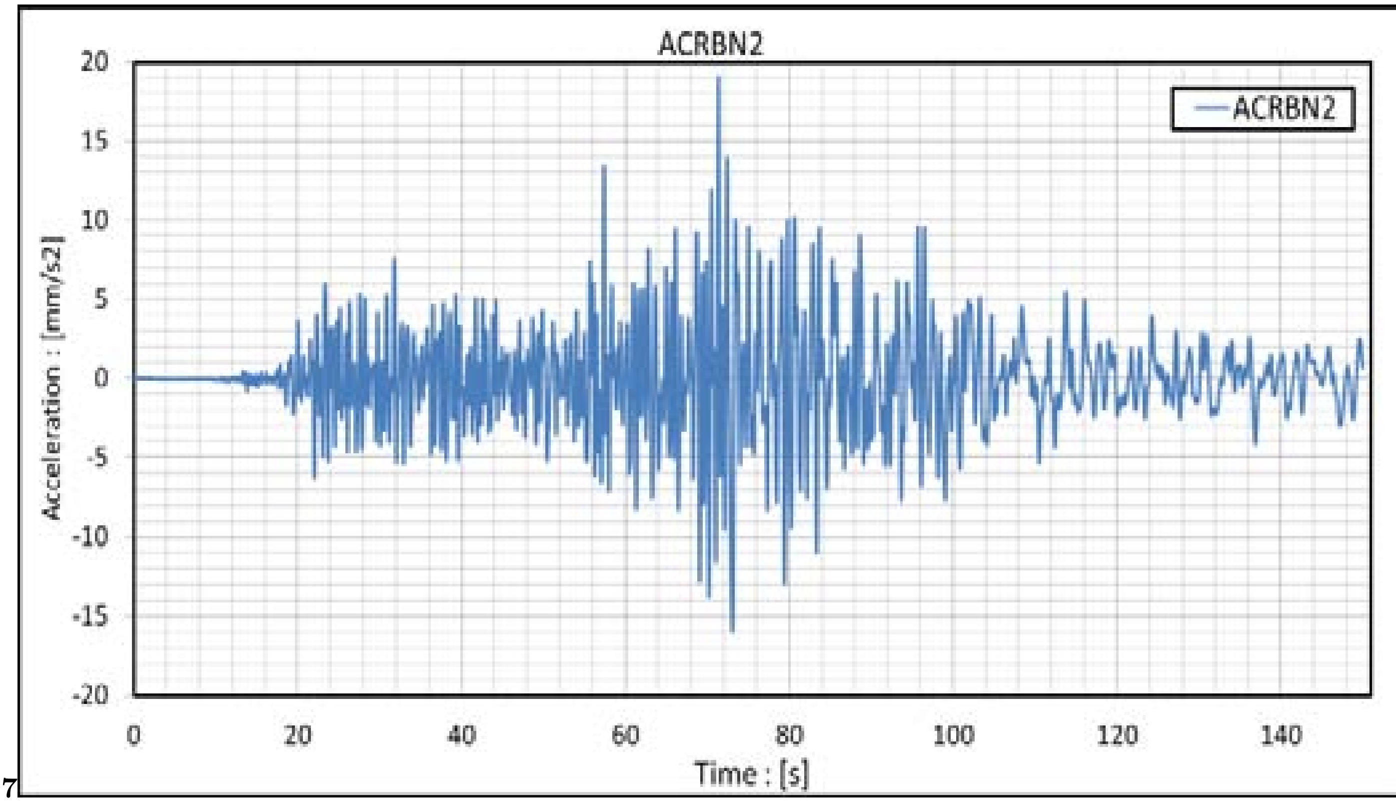


Figure 7: Figure 7 :

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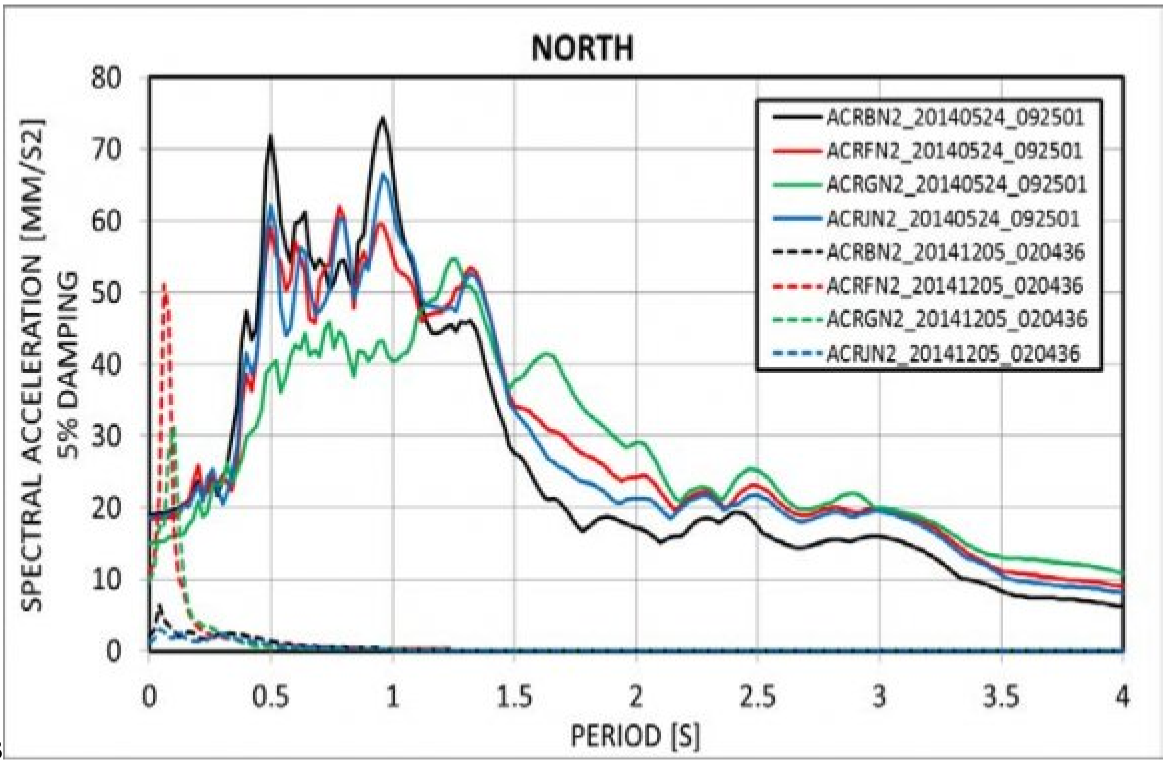


Figure 8: EFigure 8 :

Figure 9:

## .1 Acknowledgements

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