SEISMIC EVALUATION OF APOLLO 17 LANDING SITE AGAINST MOONQUAKES AND METEORITE IMPACT. H. Seifamiri[1], P. Maghoul[1], R. Boudreault[2], A. M. Jablonski[3], [1]Department of Civil, Geological and Mining Engineering, Polytechnique Montreal, hamed.seifamiri@polymtl.ca; pooneh.maghoul@polymtl.ca, [2]Canadian Space Mining Corporation, richard@techaero.ca; [3]David Florida Laboratory/Canadian Space Agency and Dept. of Mechanical and Aerospace Engineering, Carleton University, alexander.jablonski@asc-csa.gc.ca.

Introduction: With the start of the Artemis missions and the requirement to build bases on the moon, the seismic mapping of the lunar surface against diverse seismic sources is now far more crucial than ever. Different constructions for the moon have been simulated and designed in recent years using various methods and materials [1-4]. However, no seismic study of site-effects has been done for the Moon. According to studies on the seismic site-effects of terrestrial topographies, the presence of valleys, canyons, ridges, and hills, significantly can alter the seismic response of the ground's surface motion [5, 6]. To take into account the seismic effects of such topographies on the moon, no 2D or 3D seismic evaluations, however, have been carried out. Meanwhile, the lunar surface is covered with a variety of canyons, craters, alluvial valleys, and rocky mountains [7, 8]. One of the famous topographies on the moon is Taurus-Littrow Valley (TLV), which is special because it comprises both ancient highland and younger volcanic areas and for this reason, it was chosen as the landing location of the Apollo 17 mission [9]. Hence, we investigated the 2D seismic site effects of this large valley using a hybrid FEM/BEM numerical code [5, 10, 11]. We modeled this valley against the meteorite impact load and vertical in-plane moonquake in order to precisely establish the seismic response of various scenarios. This valley's amplifying effect on ground surface motion and the intricate pattern of wave scattering within LTV are revealed via these seismic 2D seismic simulations.

Seismic Simulation: In order to evaluate the core features of the seismic response of TLV, we have developed several models under different seismic excitation sources. First, we investigate the spectral amplification of TLV under vertical in-plane excitation, which is a common assumption in seismic site effect analysis. Hence, we also study the seismic response of the valley under meteorite impact seismic signal. All the simulations are carried out using SiteQuake (FE/BE) numerical program. The bedrock and half-space conditions are simulated using the classical BEM which ensures that there are no reflecting waves from boundaries, while the valley's strong heterogeneity is simulated using the FEM. The elements' mesh size is chosen to be one-tenth of the wavelength. In the BEM section, the seismic signals are imposed as displacement time histories. Also, the impactor is considered to have a 10-meter diameter.

In order to obtain the elastic seismic wave, we assumed that the TLV region was outside of any areas that could have been significantly impacted by inelastic material deformation or plastic damage from impact. According to the impact cratering laws [12], the crater opening would be approximately 10 times the impactor size and the damage range would be 4 times the crater opening. Therefore, we took into account the collision site at a distance of 500 meters from the TLV in order to model a seismic source with elastic waves.

Results and Discussion: To have a better perception of the fundamental physics of wave scattering on TLV, Figure 1 shows the result of the displacement seismogram for vertical and horizontal directions under a vertical SV moonquake signal and a meteorite impact.

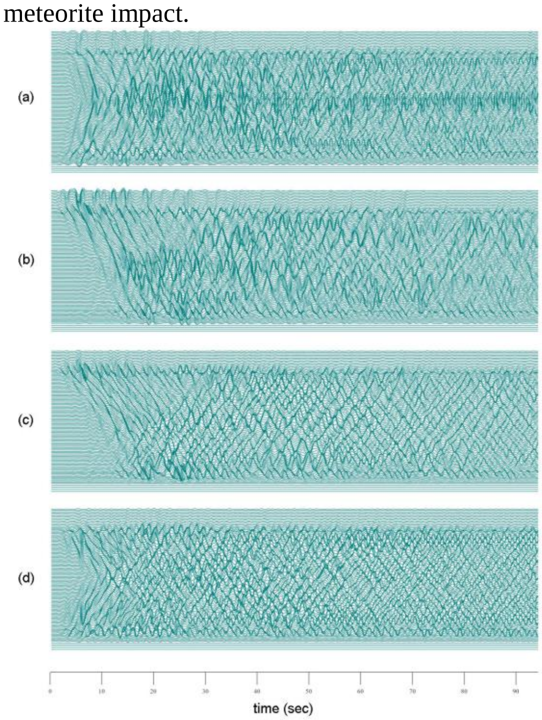

Figure 1. Displacement seismograms for the moonquake (b,c) and meteorite impact (a,d) scenarios, respectively, in horizontal (a,b) and vertical (c,d) directions.

It can be seen that in moonquakes case, the arrival of direct shear waves at earlier times starts with a lower amplitude from the edges and gets stronger at the center. This arrival, however, experiences more delay and stronger amplitude for meteorite impact at the near (the impact zone) edge.

We can observe that in both scenarios, trapped seismic waves inside the TLV contributed to the prolongation of the seismic waves' reverberation. In contrast to moonquake events, where these kinds of surface waves are formed, surface waves that arose in the meteorite impact case had higher amplitudes.

When analyzing the vertical component of motion, the refracted P wave with low amplitudes in the center and large amplitudes at the edges, which is produced by mode conversion of SV incident wave reaching the sloped part of the TLV, is the first item to be seen in earlier times. The development of Rayleigh waves in the near-edge sections of the vertical seismogram in both scenarios is another notable occurrence.

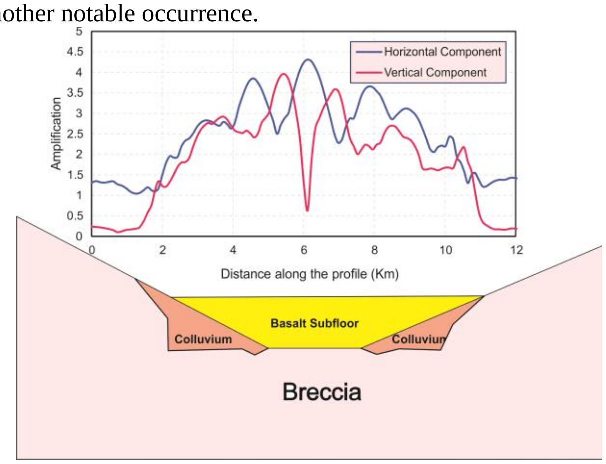

Figure 1. Amplification pattern for ground surface.

We have illustrated the Surface Amplification Factor (SAF), which is defined as the spectral ratio of the surface displacement to the spectral ratio of the input signal, for the moonquake scenario in Figure 2.

It is obvious that the SAF distribution is greater for horizontal motion, particularly in the valley's center. For the vertical component, the waves cancel each other out for vertical amplification because they reach the center with a near 90 degree phase difference.

Due to the complex subsurface of the TLV and local wave interaction that results in constructive and destructive interferences of up-down going body waves and edge generated surface waves, the location of local peaks and troughs within the basin's surface can be seen. Additionally, the TLV's edges (on the Breccia zone) exhibit less amplification than the basin's center, as can be seen in figure 3.

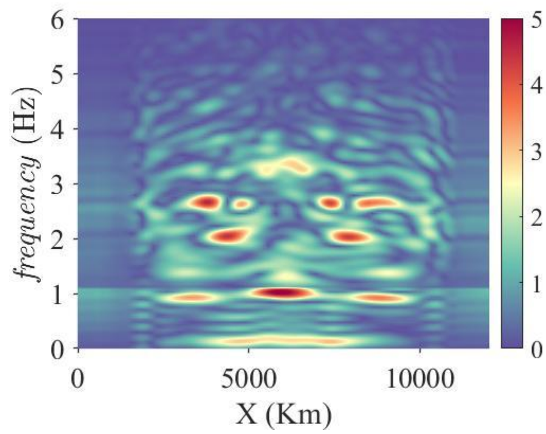

Figure 3. Frequency domain amplification pattern of TLV in horizontal direction.

Figure 3 further details the surface SAF against abscissa (x) and dimensionless frequency. Indeed, the significant role of higher modes is obvious in this figure. The 1D effect and fundamental frequency are primarily responsible for the amplification at the valley's core (the basaltic area), as can be seen in the figure at around *f*= 0.12 Hz, which is near to the 1D fundamental frequency. However, the amplification at the valley borders is mostly brought about by the lateral propagation and concentrating effects of surface (around *f*=1 Hz) waves, which play a crucial role at the valley edges for both left and right parts of the valley.

Acknowledgments:

We acknowledge the Canadian Space Agency for funding this project.

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