Mem. S.A.It. Suppl. Vol. 19, 389

Memorie della
Supplementi

Prevention of seismic damages in telescope design

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Abstract. Some of the best astronomical sites are unfortunately located in potentially seismic areas. An appropriate study to evaluate the dynamic forces acting on telescope optics is therefore crucial, to prevent them from damages in case of earthquakes. We present a procedure to estimate the response of the VLT Survey Telescope (VST) telescope primary mirror to a Maximum Likely Earthquake (MLE) in the European Southern Observatory (ESO) site of Cerro Paranal, Northern Chile.

Key words. Sesmic hazard - VST - Matlab

1. Introduction

The VST Telescope is being placed on Cerro Paranal in the Atacama desert in northern Chile. This site provides excellent conditions for astronomical observations. However, it is likely that important seismic activities occur. The telescope structure and its components have to resist the largest earthquakes expected during their lifetime, also defined Maximum Likely Earthquake (MLE), characterised by a maximum ground acceleration of 0.34 g (Koch, 1997). Therefore, design specifications and structural analyses have to take into account loads caused by such earthquakes. The present contribution shows the procedure followed in the design of an adequate safety system for the VST primary mirror.

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2. VST safety system design

The primary mirror safety system has two essential functions: a safe restraint of the mirror in all directions during an earthquake event and, during normal operations, the axial restraint in the whole altitude maintenance range (0^0 - 95^0), mandatory since the mirror axial actuators are push-only type. Independently of the actual safety/restraint system introduced for the primary mirror, the study of the performances of a telescope structure under seismic loads can be essentially performed using one of the following approaches, in order of complexity:

- equivalent static procedure
- response spectrum analysis (RSA)
- time history (transient) linear and nonlinear analysis

Equivalent static and response spectrum analyses are intrinsically linear. Nonlinear transient analysis can overcome the limits of linear

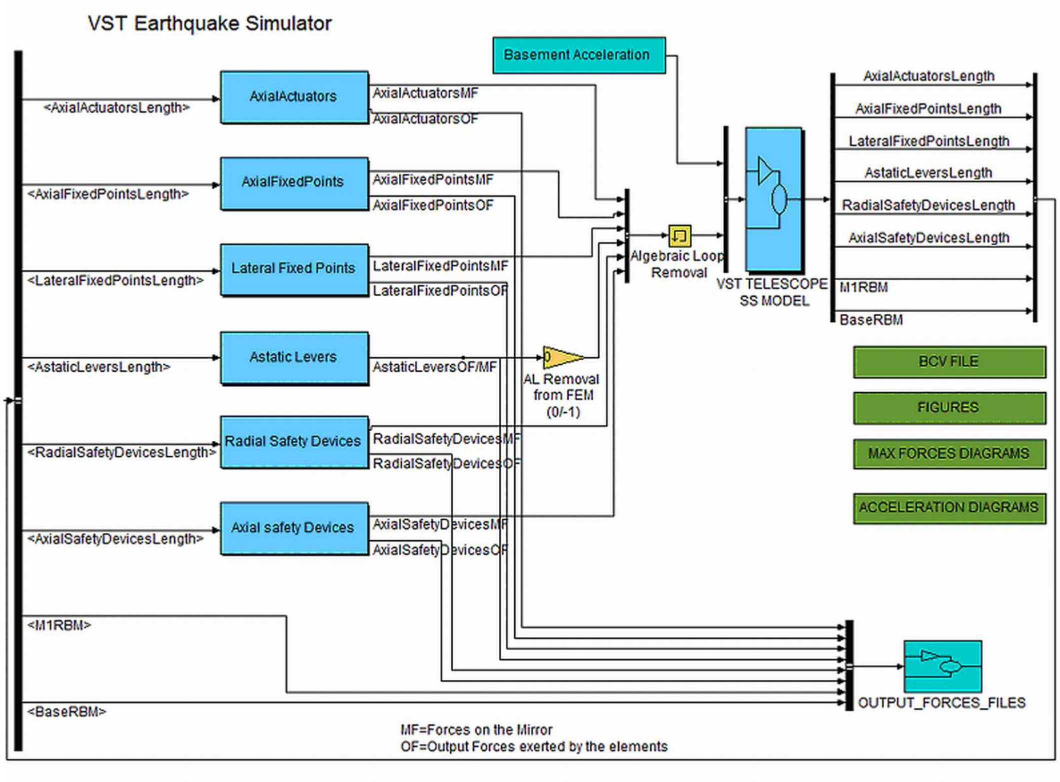

Fig. 1. The VST simulink model. The element length variations, L, output from the VST space state model, are sent to the appropriate sub-blocks, that compute the forces to be applied to the mirror according to the nonlinear characteristics of the devices. Actually each device class (axial actuators, axial fixed points etc.) has its own nonlinear behavior, and there are also differences between devices belonging to the same class. In order to remove any algebraic loop issue a delay element has been introduced in the Simulink model.

analysis, but its long computational time can be a major disadvantage. (Tsang et al. 2008). Both an RSA and a simplified transient analysis (Perrotta 2008) on the VST telescope have suggested further investigations. Most of the devices attached to the mirror are characterized by a nonlinear force-displacement curve. In addition, the safety devices have an intrinsic nonlinear behavior: they can be in contact with the mirror, acting as spring constraint, or they can be detached from it. To properly address the problem of mirror protection during an earthquake, an appropriate disposition and dimensioning of the safety devices is mandatory. In order to evaluate the stress inside the mirror during seismic events, due to the forces exerted by support and safety devices, the following procedure has been developed:

- create a linear finite element model of the telescope on its pillar, including the cell with all the devices surrounding the primary mirror.
- export this model, using a dedicated software, developed by the European Southern Observatory (ESO), to Simulink, with a state space representation.
- create a Simulink nonlinear model of the safety and support devices, linked to telescope model. For the VST case, two different telescope service configurations have been taken into account as limit cases (Elevation $0^0/90^0$).

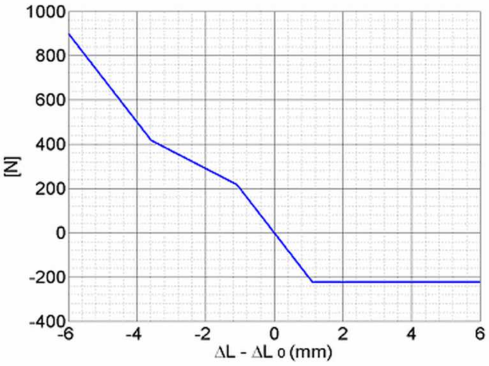

Fig. 2. Axial Actuators nonlinear differential force-displacement characteristic.

- perform a nonlinear transient analysis inside Simulink, using as input random generated acceleration - time histories compatible with telescope site seismic spectra.
- read the results of the previous step, that is time histories of forces exerted on the mirror by the devices and mirror accelerations and apply them as external forces and accelerations to a Finite Element(FE) model of the primary mirror, solving a proper number of static analyses.

2.1. Transient analysis

The transient analysis has been performed using a mixed FE/Matlab approach. A linear FE model of the telescope has been developed, with all nonlinear devices represented by linear spring elements whose stiffness is the initial stiffness of the nonlinear force-displacement curve. For the safety devices, spring stiffness has been set equal to stiffness of the safety itself. This model has to be exported to Matlab/Simulink, using a space state representation (Schipani et al. 2006). All nonlinearities are then appropriately built in Simulink (Fig. 1) and a simulation in the time domain is run. The State Space Model of the telescope structure is based on the first 200 modes: 197 flexible modes and 3 rigid body modes, translation along global z, x, y direction (global coordinate system concide with cell coordinate system when telescope points toward zenith, X cell is the altitude axis, Z cell the optical axis, Y cell normal to both). These are the modes corresponding cumulatively to more than 90% of modal masses along z, x, y direction, giving a response up to 150 Hz. According to Paranal response spectrum, Maximum Likely Earthquake (MLE) highest significant frequency is about 40Hz (Perrotta 2008).

2.2. Static analysis and results post-processing

A 3D FE model of the mirror has been realized, with solid elements. Proper surfaces corresponding to the nominal interfaces with supporting assemblies have been defined onto the mirror model. Forces exerted at the same instant at all interfaces have been applied simultaneously on relative application surfaces as nominal distributed pressures. In order to provide an accurate description of stress state in areas with high stress gradient the ”submodeling” technique has been adopted. Results of full transient analyses consist of acceleration and force histories for each of the about 150 devices connecting (or more generally interacting with) the mirror to (and) the cell. Two different telescope service configurations have been chosen and two random generated acceleration histories (compatible with the chosen seismic spectra) have been applied to each configuration, for a total of 4 transient analyses. Each transient analysis envisages the application of seismic time histories about 32 sec long. A sampling frequency of at least 1/1000 is required to catch local history peaks avoiding annoying aliasing. Subsequently, the results of each of the 4 performed transient analyses consist of about 150 force histories (+3 acceleration histories) sampled in 32760 steps each. Performing a simple static analysis for each step would mean performing a total of 131040 solution steps. To select only a subset of time steps the following criterium has been used: a threshold value for each force (acceleration) history is stated (expressed in percentage of the maximum and minimum registered values) and only steps involving at least one device (or ac-

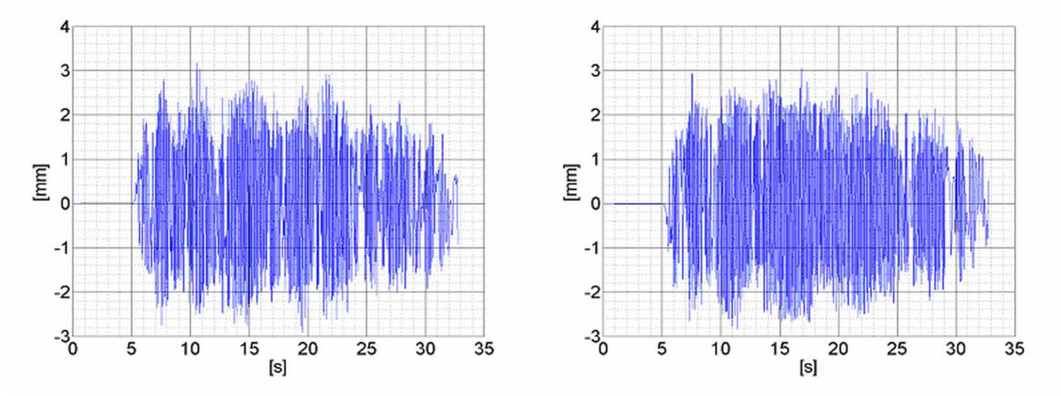

Fig. 3. Mirror-cell relative displacement along cell x axis (telescope altitude axis, or global X axis): telescope pointing to horizon (left) and zenith (right).

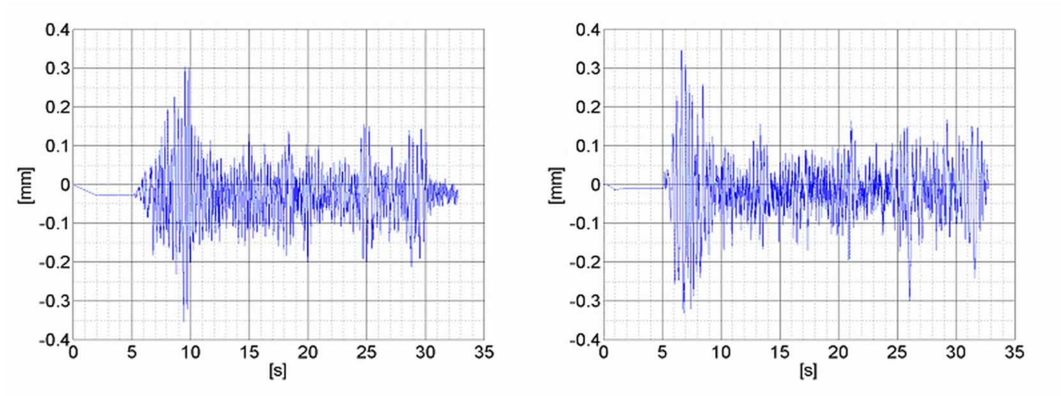

Fig. 4. Mirror-cell relative displacement along cell y axis (cell z axis coincide with optical axis): telescope pointing to horizon (left) and zenith (right).

celeration component) exceeding the threshold force (acceleration) value are processed. The calibration procedure of the threshold value finalized to get a desired number of steps is a non trivial problem. Force values registered (from the same time history) for a single device show distributions not fitting the most common distribution probability curves (such as normal/log-normal). Consequently confidence interval approaches are not applicable and numerical procedures cannot be easily implemented. For this reason calibration has been carried out with subsequent manual converging steps starting from random values.

Acknowledgements. The authors would like to thank Michael Mueller and Franz Koch from the European Southern Observatory, who suggested to model telescope nonlinear elements inside Simulink and provided the software for the export of the telescope linear FE model to Simulink.

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