Enclosure and infrastructure requirements for OWL: possible solutions.

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ABSTRACT

The paper discusses the requirements of the enclosure and infrastructure for OWL. Although predicted to have no serious technological risks, these items will constitute a significant investment within the OWL project. An enclosure for such a large telescope does not have to provide the same functions as the actual enclosures built as of today. Protection from wind disturbance is not provided as efficiently as by enclosures with dimensions in the order of 30m. The conditioning of such large volumes is economically not viable. A none co-rotating enclosure is shortly discussed as a solution and the reasons, which could make it effective are analyzed. The pier of the telescope is sketched and its effect on the telescope dynamics is discussed.

Keywords: Large telescopes, Enclosure, Infrastructures, Wind.

1. GENERAL INTRODUCTION

We introduce the discussion on the feasibility of an enclosure for a 100m telescope, which can be built at reasonable cost and still provide the needed sheltering of a telescope. We also elaborate on the impact of the concrete infrastructures, taking into consideration the influence geo-technical properties of the soil, and their influence on the dynamic behavior of the telescope.

A primary goal of this study is to limit the cost impact of such structures on the project to the minimum, not only as capital investment but also for maintenance and operations in the case of the enclosure. For this reason the enclosure should be as small and as simple as possible, with the functions implemented as close as feasible to the ground level, and therefore easily reachable for maintenance, with the least number of mechanisms. It shall perform the functions of protecting the telescope from sun exposure during the day, shelter the telescope from survival wind and from rain or snow. It should leave the functions to other specialized constructions, which are until now performed by the co-rotating enclosures, of protecting from wind during operations and to keep the telescope at the forecasted air temperature during the night if they cannot be performed economically or efficiently. Based on the above considerations the enclosure for OWL can be envisaged as a huge but simple hangar which, sliding on rails, is moved apart to allow observations. This type of sheltering structure is not new in astronomical application, see for example the first concept for the ESO VLT. Yet, until today, economical affordability of co-rotating enclosures has lead the final choice to this type of construction, the reason being mainly the efficient protection from wind disturbance while observing. In the following we will elaborate on a possible none co-rotating enclosure for OWL.

Another point in the design of a telescope that deserves great attention, without hiding any technological risk, is the concrete supporting pier. The concrete structure and the soil are integral part of the dynamic chain, which defines the control bandwidth of the axes of the telescope. Therefore its design needs to be developed considering its effect on the system, and not only as a separate package belonging to a different engineering discipline.

2. ENCLOSURE FUNCTIONS

The ideal enclosure should provide the following functions:

- Smallest possible enclosed volume and developed surface for economic reasons (the cost of such buildings can be considered proportional to the developed surface).
- Protect the telescope from solar exposure during the day, from extreme environmental conditions like survival wind load, rain and/or snow.
- Protect the telescope from wind disturbance during observation at any operational angular position.

- Keep the inner temperature at a convenient level, so that the telescope structure and optics are at thermal equilibrium with the external environment at the start of the observation. In this way the telescope induced seeing is minimized.
- Minimize the so-called "dome seeing". This function is obtained in modern enclosures by letting the air flow inside the enclosed volume, so that the structural parts and the floor surrounding the telescope quickly reach and thermal equilibrium with the external environment.

The last two functions reduce themselves mainly to spend energy to remove heat from materials, and to remove steady buoyancy bubbles generated inside the enclosed volume.
The classical co-rotating enclosure, both cylindrical and spherical, built for the telescopes up to the 10m class provide most of the functions listed above.
Rotating buildings with the characteristic dimensions of about 30m maximum can be built with reasonable capital investment, although enclosing larger than strictly needed volume. The thermal conditioning of the enclosed volume, typically in the order of 25,000 to 30,000 cubic meters, can be provided efficiently with reasonable power consumption. The dimension still allows convenient maintenance access. The observing slit/opening is never more than 1/3 of the characteristic dimension. This leaves enough structural material to provide sufficient torsional stiffness of the construction to avoid deformations during the rotational motion, which could hinder the motion itself, especially if enclosure deformations add up under wind load.
The most important function of co-rotating buildings of this class is undoubtedly efficient protection from wind disturbance during observation, mainly by means of permeable windscreens incorporated in the observing slit. This statement must be better detailed, because the windscreens, while decreasing the DC component of the wind speed, move the turbulent spectral content to higher frequency, obtaining the effect of increased disturbance on the tracking. ESO has performed a number of wind tunnel studies to determine the wind turbulence spectra inside an enclosure at different wind attack angles and at different windscreen protection. The studies confirmed that the Von Karman spectrum represents the turbulent flow both in open air and inside the enclosure. The turbulence intensity and the turbulence integral length in the different situations have been determined and the spectra for the extreme cases of open air, and windscreen up are shown in Fig.1. It can be noted that the presence of the enclosure and the windscreen increases the contents of wind energy above 0.2 Hz, which is not beneficial to the telescope tracking, especially if the telescope has high locked rotor eigenfrequencies.

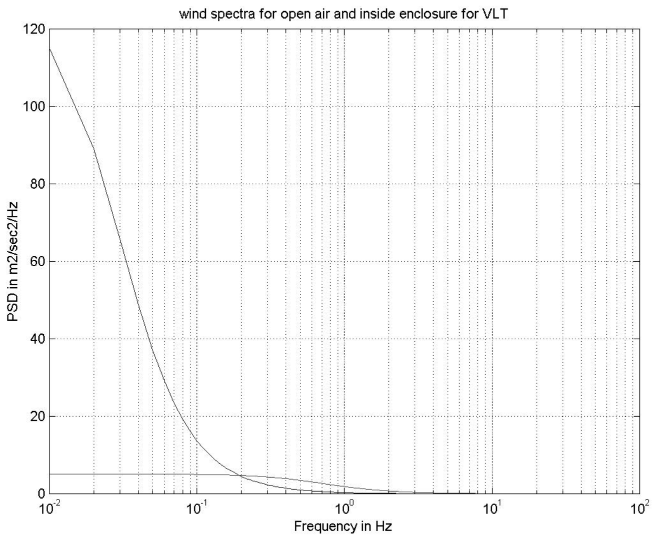


Fig. 1: Von Karman wind spectra.

On the other hand, both the enclosure and windscreen at the primary mirror level perform efficient protection from wind disturbance. In this case, the mirror figuring which is largely dependent from wind pressure deformation is well preserved and it is the main reason for which co-rotating enclosures have always been preferred, if economically affordable, in the telescope domain.
In conclusion, while the mirror figuring preservation would always call for a co-rotating dome, although also a fixed protection could be considered, the other functions could well be performed by a none co-rotating enclosure. Once opened, it would not cause local dome seeing, and would allow the telescope structure and optics to use the natural ventilation to reach thermal equilibrium with the external environment.

3. ENCLOSURE FOR A 100M TELESCOPE

Following the experience accumulated for 10m class telescopes, in the first instance, the possibility to build a co-rotating enclosure for OWL is a tempting idea. On the other hand, assuming to scale up the cost of a 100m telescope enclosure proportional to the enclosed volume, it brings investments that would discourage such an approach. (An enclosure similar to

the one at the VLT, would enclose about 7 million cubic meters against the about 25,000 cubic meters of VLT, and would develop about 200,000 square meters of surface instead of about 4,000 square meters.
Moreover, a number of considerations about the functions to be performed deserve to be discussed, specifically:

- The efficiency in protecting the primary mirror and the telescope from wind buffeting is debatable and shall be studied in detail.
- The conditioning of volume which is in the order of 2 to 7 million cubic meters would definitely result in extreme economical burden both for the installations and for the power generation plant dimensions.
- The aspect ratio of the observing slit to the characteristic dimension of the enclosure will be close to 2/3, that is not much structural support is left to provide the stiffness needed during motion, unless the enclosed volume is increased more than what strictly needed, increasing the cost.

To assess the first point will require detailed studies about the fluid dynamics inside large enclosures, where it means of the same dimension of the vortex typical in open air (about 80 to 100m). Based on general considerations, it seems that the protection of the primary mirror would be efficient, while protection of the secondary structure from turbulence would be less efficient because of the circulation of the vortices due to the large dimension of the volume.
The second point is purely economic, but also speaks in favor of dedicated constructions to perform functions that are needed locally. Conditioning is the typical example. OWL plans to have local smaller conditioned volumes to keep the primary mirror at the desired temperature to avoid local seeing degradation. The structure of the telescope is designed for low thermal time constant, which allows the telescope to reach thermal equilibrium with the atmosphere shortly after the opening of the enclosure.
The third point is a matter of structural design, but the ratio between openings and continuous structural parts is relatively unfavorable, especially if the volume enclosed has to be kept at the minimum.
Based on the above, it has been thought, as a first approach, to consider a none co-rotating enclosure for OWL, composed of two halves sliding on rails, leaving the telescope in open air during operations. In Fig.2 a schematic view of the enclosure with the rails and the telescope pier is shown in comparison with the VLT Telescope area at Paranal.

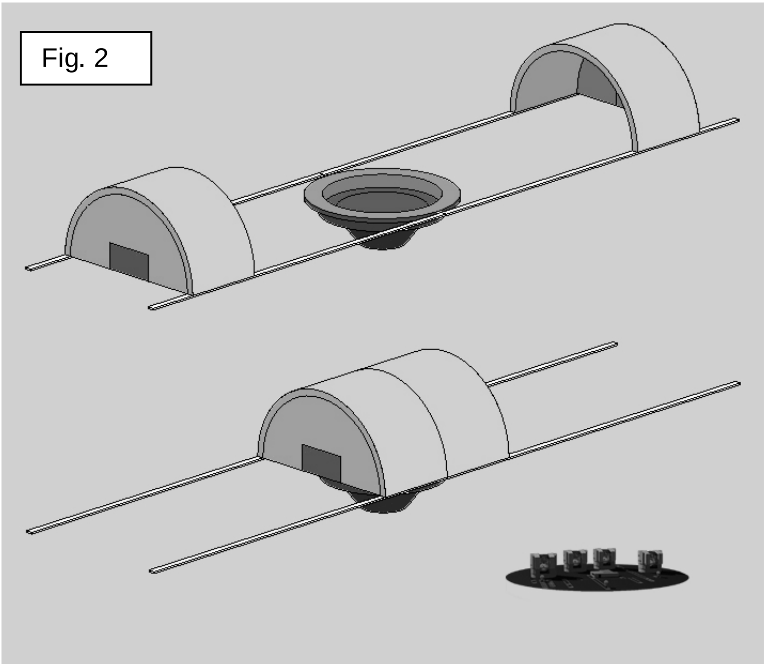


Fig. 2

The preliminary choice to consider for such a solution is based on the following considerations:

- OWL will be horizontally parked; therefore the height of the arch will be the smallest possible (about 90m outer diameter).
- The volume enclosed will be the minimum possible for an enclosure (in the present case about 2 millions cubic meters and 36000 square meters covered area), and the structure can be designed to allow natural ventilation during the day.
- The mechanisms will be kept at the minimum, and almost all functions can be installed close to ground level (motion system, power distribution, etc.)
- The protection of the telescope from wind buffeting can be implemented, if needed, with fixed installations placed conveniently (although its needs to be determined if such a measure can efficiently protect the telescope, or if the telescope has to be designed to take care of full wind disturbance rejection).

The drawbacks of this concept is mainly in the dimensions of the site needed to accommodate the full stroke of the enclosures halves to leave the telescope out of their wakes. The rule of the thumb says that the wake fades away in a distance that is about three times the obstacle dimension facing the wind. In this case the enclosure has to be moved about 300m far from the telescope. All summed up the site will need a plane area of about 1x0.4 km square. The vertical walls

closing the two halves could be designed to allow wind flow through—so that to open, or to close, the enclosure with wind will not require high forces and large motors. Just as an indication with a wind speed of 10 m/s directed along the sliding direction, and an opening time of 20 minutes it would require for each half a power of about 210kW, if the wall is solid.
Assuming a survival wind speed of 50 m/s the enclosure will experience a force to be discharged to the rails of about 21 MN along the sliding direction and of about 12 MN along the perpendicular direction, due to a more favorable drag coefficient. Finally it seems that the concept of a double hangar holds and is feasible. It may also be integrated with a local windscreen with the only aim to protect the primary mirror from direct wind pressure.
It is worthwhile to mention that such an enclosure design is not new in optical telescopes field. The VLT enclosure has been thought, at the beginning of the project, to be composed of four hangars sliding on rails, being the least expensive way to protect the VLT telescopes. While the VLT project progressed, this solution has been abandoned in favor of an open air cupola which had the advantage to use less space and to reduce the demands on site development. At the end a fully co-rotating enclosure has been realized, mainly because the primary mirror figuring during observation required to be protected from direct wind pressure.

4. ALREADY EXISTING BUILDINGS OF COMPARABLE SIZE

Another reason which encouraged to consider the concept presented above, is that large buildings of the same size, or even larger, have been designed and built in the past and one is being built presently.
The dirigibles industry dealt with design and building large enclosures to be opened since the beginning of the last century. Also today in Brand, near Berlin, Germany, a large factory of dirigibles is being built. (Fig.3).
The building is 360m long, 220m large and 107m high, it covers an area of 66000 square meters and encloses a volume of 5.5 millions cubic meters, more than twice of what the OWL enclosure would require.

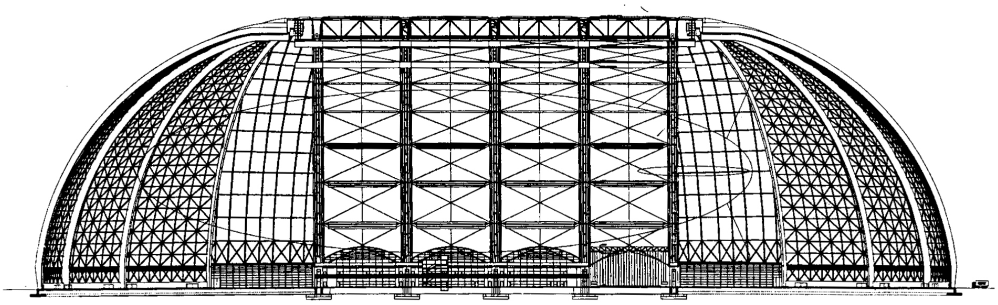
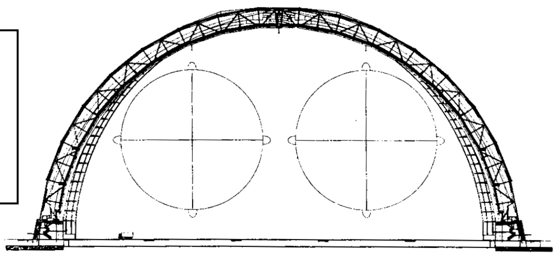


Fig. 3: dirigibles factory in Brand.
(courtesy of SIAT Germany, Dipl. Ing. M. Hautum, Dipl. Ing. Verena Thiels)



The right and left sides, shaped as quarter of a sphere, can be opened to let the dirigibles out when they are completed. It can be noted that the movable parts show diagonal bracing's to stiffen the parts to withstand the motion without deforming. The cost of this type of construction is proportional to the developed outside surface and it is in the 600 EUR/m^2 range.
Other buildings with even more demanding requirements have been designed and studied. An example is the protection sarcophagi of the damaged nuclear reactor of Chernobil in Ukraine (Fig. 4). Due to the high level of radiation it is impossible to work directly on the reactor. Therefore the arches, which form the complete building, 81m radius and 30m long each, are built far from the final location and then are sled on rails to the final position. The safety requirements of such a construction are extremely high and the working conditions extremely difficult. The final cost has been estimated in about 200 MEUROS. The completed construction will cover about 45000 square meters, will enclose about 3 millions cubic meters.

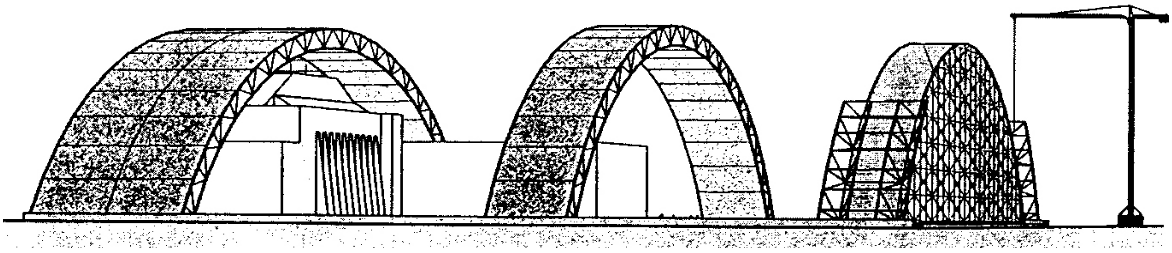


Fig. 4: Chernobil reactor protection sarcophagi (article in Bauingeniuer 1999 Nr. 6)

Also examples of sliding cover of the dimension interesting for OWL exist. In Miyazaki, Japan an artificial sea resort is equipped with a cover which can be removed to let the sun through (Fig.5). The two halves are made of three telescopic segments each, which slide on each other. The covered area is about 300m long and 160m wide.

Fig. 5: Seagaia sea resort. Miyazaki, Japan

Other examples of movable covers are to be found in modern stadiums. In Venice one such installation is planned, which will be completely covered, and the total cost is estimated at about 80 MEUROS.

5. TELESCOPE PIER

The telescope pier is directly part of the stiffness chain, together with the soil, which defines the bandwidth of the telescope axes control. The pier transfers to ground all the reactions to the control torque delivered by the main axes drives. Every rocking movement of the pier on the soil or due to intrinsic insufficient stiffness will show up in the Bode plot for altitude axis. In fact both tachometers and encoders measure the relative speed and displacement between telescope tube and

telescope azimuth structure, whose movement is also defined by the stiffness of the pier itself and the geotechnical properties of the soil. For the azimuth axis the torsional stiffness of the pier comes directly into play for the same reasons.
Therefore it is essential to design the pier in such a way that the system pier+soil behaves as a stiff unit with respect to the telescope itself. Ideally the lowest eigenfrequency of the telescope on infinitely stiff supports should not change more than few percent when the real pier and soil are introduced in the model (for the VLT we obtained the excellent result not to have any degradation of the eigenfrequency at Paranal, where the soil Young modulus is about 45000 Mpa).
To reach this goal it is necessary that the loads transferred to the concrete be evenly distributed, to avoid local deformations of the concrete itself. Consequently the pier must transfer the whole load to the soil evenly and distribute it on an area, which, according to the elastic characteristics of the terrain, will assure the desired stiffness.
It appears clear that a stiff, compact type soil will result in a more limited need for large foundations, and finally in more economic construction.
Based on the above considerations, a static analysis has been performed to assess preliminarily the stress level and the deformation of the concrete under the telescope gravity load. To obtain a more complete result the portion of terrain embedding the pier has been modeled as elastic, homogeneous and isotropic.
Two cases for the soil have been considered, and none as good as Paranal, namely a "stiff" soil with Young modulus of 25000 Mpa and a "weak" soil with a Young modulus of 2500 Mpa. For information the first is equivalent to good concrete and the second to a mediocre soil. In both cases the terrain is considered compact, that is good for hankering directly the pier to the soil with micropoles.
A quarter of the pier has been modeled as in Fig. 6. As first guess it is designed as a 5m thick axial-symmetric structure
It is loaded symmetrically with a force system, which represents the actual distribution of the reaction forces determined in the FEM analysis of the telescope for a total load of 30,000,000 N (about ¼ of the telescope weight). Static analyses have been performed under the following conditions:

- Stiff soil, telescope load only
- Stiff soil, telescope+pier own weight
- Weak soil, telescope load only

The aim was simply to understand whether larger than usual quantity of reinforcement had to be used, to determine the order of magnitude of the deflection of the system pier+soil under the telescope load, and to assess preliminarily the possible effects of soil elasticity on the design.
Figs. 7, 8, 9 and 10 show the results relevant to our investigation, which can be summarized as follows:

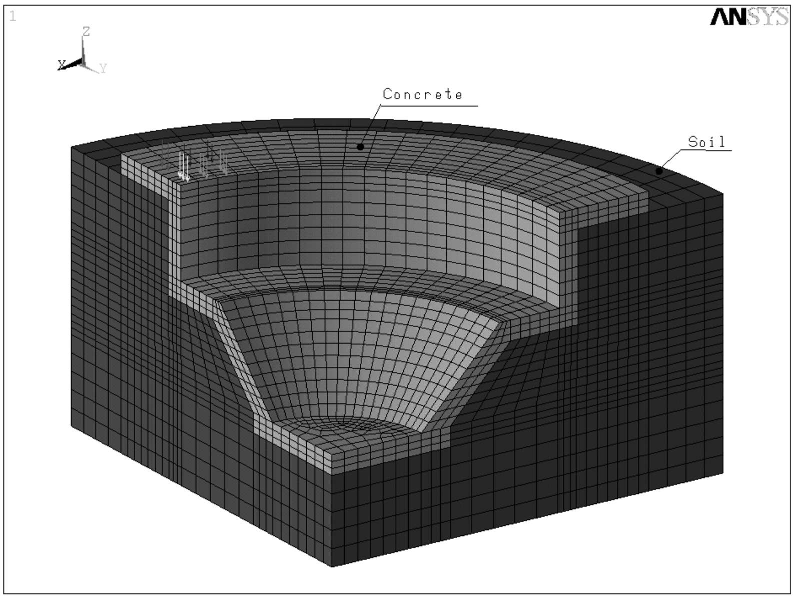


Fig.6: Model of the pier+soil

- The deformation due to the telescope load is in the range of 0.5mm in case of weak soil, and of about 0.2mm in the case of stiff soil. This is equivalent to concentrated stiffness at the vertical boundaries of the telescope, due to pier+soil, of about 6e10 N/m, and of about 1.5e11 N/m respectively, twice because of symmetrical reasons, and practically larger because the deformation is decreasing far from the largest deflection point.
- The tensile stresses are in the order of 0.3 MPa, when only the telescope load is considered, and slightly lower when the pier own weight is taken into account, because it works as compression pre-stress. The consequence is that no special reinforcement is needed and a percentage of reinforcement in the usual range of 2 to 3% can be used.
- The compressive stresses are in the order of 0.4 MPa, which shows a good distribution of the telescope load, and does not cause any worry for the concrete behavior.
- The compressive stress including the pier own weight is in the range of 2MPa. It shows an evident over dimensioning of the slab thickness, whose optimization will beneficially reflect in the cost of the construction.

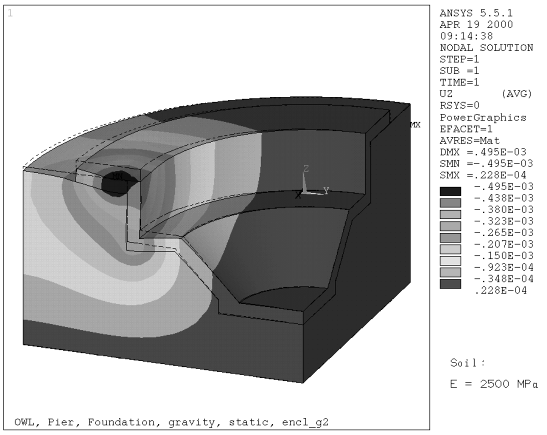


Fig. 7: Vertical displacement
weak soil

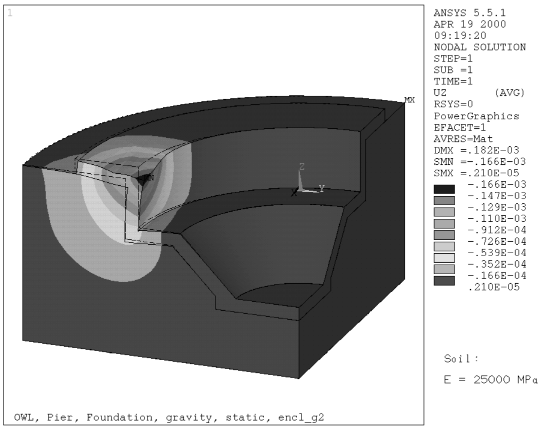


Fig. 8: Vertical displacement
stiff soil

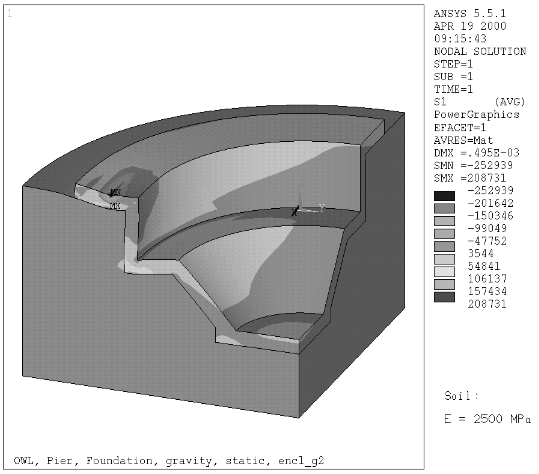


Fig.9: Largest Tensile stresses

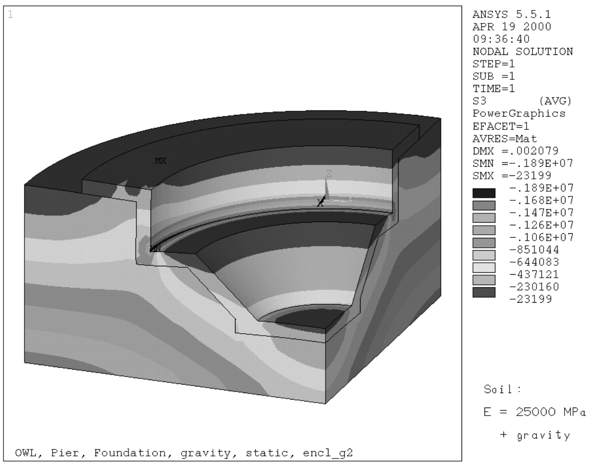


Fig.10: Largest Compressive stresses

The preliminary calculations performed here indicate that no major technical problems are to be expected in building a telescope pier which will not degrade the dynamic performances of the telescope, and without facing special structural difficulties.
After optimization one expects to pour about 150000 cubic meters of concrete, reinforced with about 36000 Tonns of steel.
In the case that the soil is largely fragmented or not compact of course the design of the pier would look much different. The soil would not allow the direct hankering and therefore large foundations slab and ribs need to be built.
Technically a solution can be found even in this case, but the material quantity, the framework, the excavation work may be up to 2 times higher than the solution considered here. It is also possible that the geomechanical characteristics of the soil are much worse than those used above, in which case a careful system analysis must be carried out to correctly assess the impact on the telescope axes control.
The enclosure rails will also need concrete foundations and hankering to the soil. In the concept considered here this will result in about 30000 cubic meters of poured concrete and 10000 Tons of reinforced steel.
The extension of the enclosure rails will require a suitable site, to avoid large leveling works with the consequent costs.

6. CONCLUSIONS AND NEXT STEPS

This paper is just a first step in organically discussing the requirements and the problems linked to the design of enclosure and infrastructure of OWL.
Based on the already existing buildings in the world, the enclosure considered is feasible and reasonably economical. The concrete pier does not show great difficulties.
It will be important to develop the design always keeping in mind the strict relations between soil, concrete and telescope.
The next steps we plan to perform can be summarized as follows:

- To detail further the design of both enclosure and infrastructures to reduce uncertainty on costs.
- To analyze the wind loading of the telescope on a site with opened enclosure.
- To assess the feasibility and efficiency of windscreens to reduce the wind load on the telescope.

7. ACKNOWLEDGMENTS

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