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NON-LINEAR LIFT-OFF AND SLIDING ANALYSIS OF PARTS OF THE CMS-DETECTOR FOR THE LOAD CASE EARTHQUAKE

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ABSTRACT

CERN, the European Laboratory for Particle Physics, is currently re-equipping the former LEP tunnel for the Large Hadron Collider (LHC) project. LHC will be ready in summer 2007 for proton-proton collisions. Several high energy physics experiments are situated along the accelerator ring in huge underground caverns. One of those experiments is CMS, the Compact Muon Solenoid. Safety related components of CMS like the Hadronic Forward calorimeter (HF) tower and its end cap are analysed for the load case earthquake.

The earthquake is defined for the site as a spectra which – after generation of time histories – is deconvoluted to the different levels of foundations and down to the tunnel in approximately 90 m depth.

The HF tower consists of 4 risers, each 18 t, a platform with 30 t and the CMS detector including shielding mass with 220 t. Risers and platform are connected by 4 swivel points, which allow all rotations and selected displacements. By a series of linear and non-linear global and local calculations the HF tower was analysed. The global stability (no topple over) is guaranteed. Some improvements in the design of the swivel points were recommended.

Each CMS end cap has a diameter of 14 m and is built from three independent disks. Due to the axial magnetic field the two inner disks must withstand a force of 85 MN and resist the large bending moments induced during operation. Therefore these disks are 600 mm thick, whereas the outer disk is 250 mm thick. Each end cap weights 2300 t.

The critical states for the load case earthquake are during the assembly and the storage in the assembly hall, where the end cap stands without any further horizontal support. By means of a non-linear analysis, lift-off, topple over and sliding is investigated, in order to receive the displacements and the forces.

Keywords: Non-linear analysis, earthquake, components.

1 INTRODUCTION

CERN, located near Geneva in Switzerland, is the European Organization for Nuclear Research, the world's largest particle physics centre. Here physicists come to explore what matter is made of and what forces hold it together. CERN exists primarily to provide them with the necessary tools. These are accelerators which accelerate particles to almost the speed of light and detectors to make the particle visible. Founded in 1954, the laboratory includes now 20 Member States.

For the Large Hadron Collider (LHC) project, the existing LEP tunnel with 27 km in circumference will be used. The tunnel avoids environmental conditions, such as humidity and temperature to which many of the components are sensitive. In addition the approximately 90 m of soil above the tunnel serve to reduce the flux of cosmic rays entering the detectors – which could be mistaken for real physics events.

A part of the LHC is the CMS (Figure 1), the "Compact Muon Solenoid", a detector for particle physics, which is based around a magnet system, using a large superconducting Solenoid, with a length of around 12 m and an inner diameter of about 6 m. It will be the largest magnet of its type ever constructed. The complete CMS detector will be about 21 m long, with a diameter of about 16 m and will weigh in excess of 12500 t. For operation the CMS will stand in an underground cavern, which is a part of the LEP tunnel. The use of a large surface hall enables the construction and testing. A modular design allows CMS to be constructed, tested and transported to the cavern in pieces.

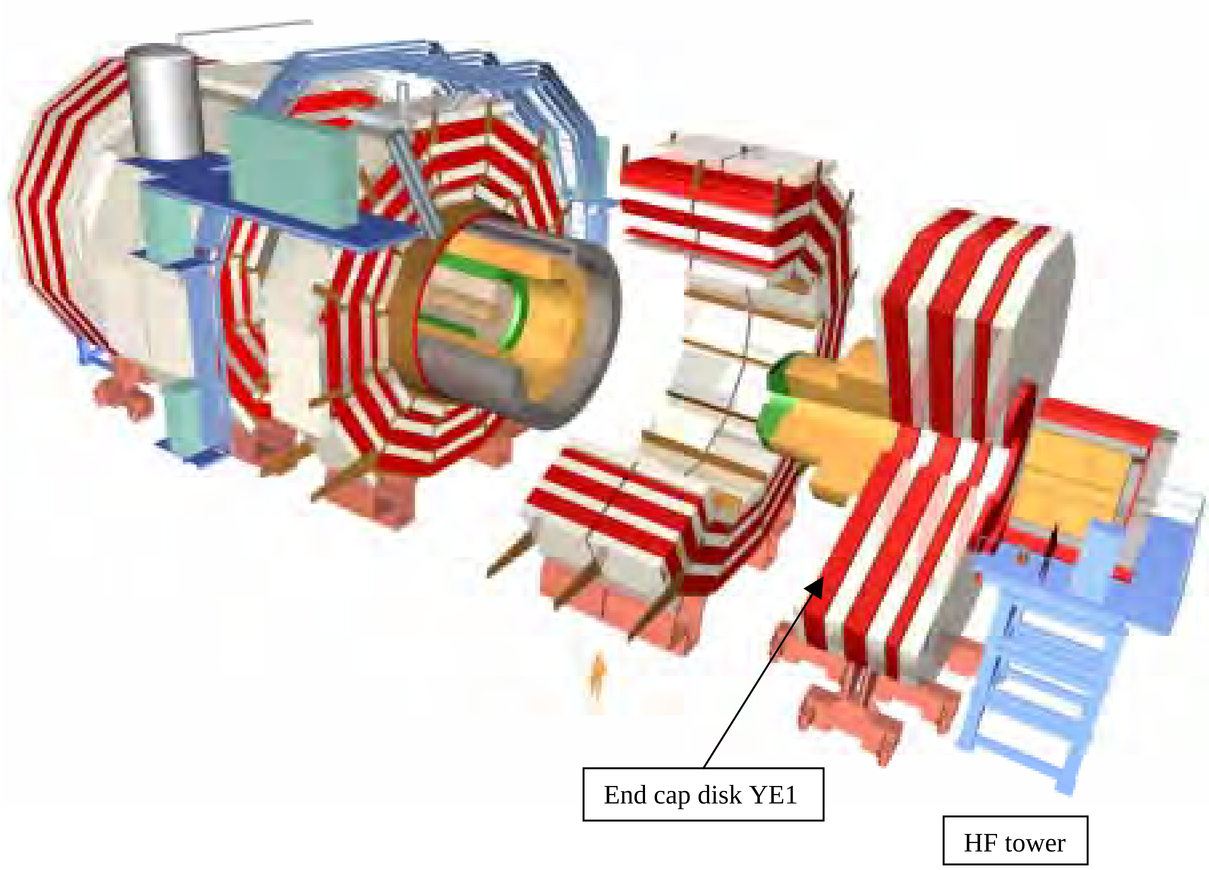

Fig. 1: CMS detector

Safety-related components of the CMS are analysed for the load case earthquake:

– the separate standing part of the CMS detector with its support, the HF tower while standing in the cavern
– the end cap disk YE1 while standing separate in the surface hall

2 EARTHQUAKE EXCITATION

The earthquake is defined for the site as a spectra at the top of the rock in 46 m depth (Figure 2). For bore holes the soil stratigraphy and moduli are given from the surface down to the level of the cavern in approximately 90 m depth. Moraine deposits and molasses deposits above the rock are strongly layered. The earthquake excitation is deconvoluted from the surface of the rock down to the depth of the cavern and up to the foundation of the surface hall. This is done by a time history generated fitting to the regulatory envelope spectrum and then used for sub-surface wave-propagation. An iterative procedure is used to account for the nonlinear behaviour of the soil. By variation of the soil stiffness error margins are considered.

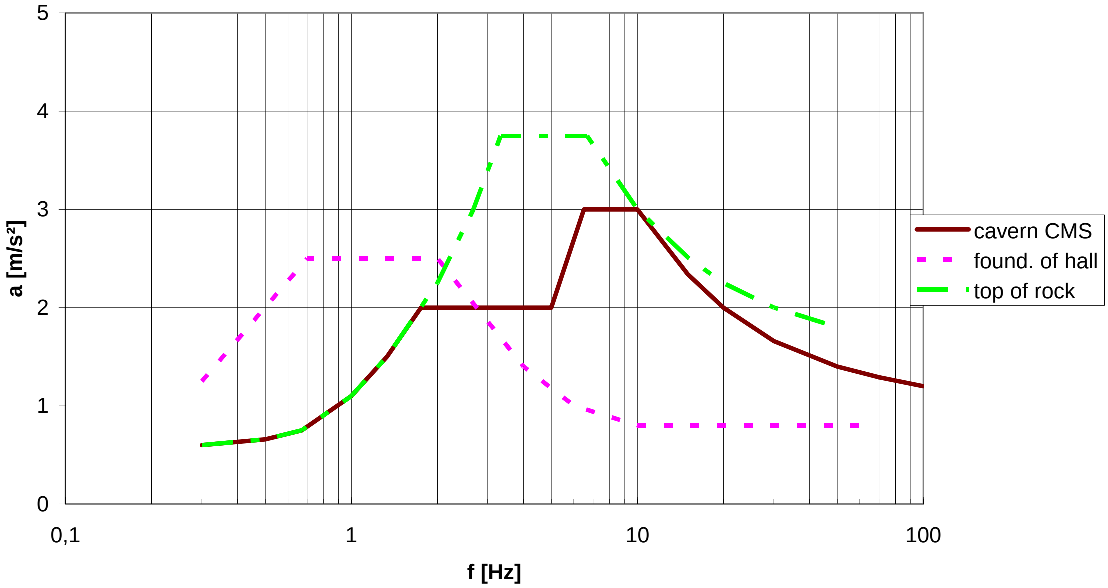

Fig. 2: Design spectra at CMS, horizontal, D = 0.05

Figure 2 shows the comparison of the enveloped and smoothed horizontal design spectra at the different levels. Because of the situated rock the spectra at the cavern is in the frequency range of 2 to 7 Hz lower than the given spectra at the top of the rock. According to the weak soil layers above the rock the increasing region of the spectra at the foundation of the surface hall is in the low frequency range of 0.7 to 2 Hz.

3 HF TOWER

The investigated HF tower consists of 4 Risers with masses 4 * 18 t, a Platform with mass 30 t and CMS-Detector including shielding with mass 220 t. Risers and Platform are a box-type construction of steel material Fe 360. The Platform is filled with concrete in the region below the detector. Risers and Platform are connected each by 4 swivel-points. The lower Riser is fixed to the base also by 4 swivel-points. The swivel-points allow all rotations to reduce constrained forces.

For dynamic analysis the structure is modelled with finite elements (Figure 3). The swivel-points and the connecting beams of the Risers are rendered by beam elements and rigid links. In the area of the swivel-points shell elements are used for the Risers. The Platform is modelled by beam elements. The detector is rendered as mass point in the relevant centre of mass, which is connected to the Platform by a rigid system. The rotating inertia masses are also considered. For earthquake all swivel-points are connected horizontally and vertically for simulation of the ball joints.

Eigenvalues and eigenmodes of the system are assessed. Displacements, accelerations, beam element forces, stresses in shell elements and reaction forces due to earthquake loads are calculated on basis of the design spectra at the cavern. The maximum responses are analyses by use of the complete quadratic combination CQC with all the 23 modes below 100 Hz. The directional responses are combined as square root of the sum of the squares SRSS.

The eigenmodes of the structure begin with frequency f = 2.90 Hz in horizontal transverse direction (Figure 3); f = 3.54 Hz in horizontal longitudinal direction and f = 8.64 Hz in vertical direction. The check of the reaction forces gives, that the vertical forces due to earthquake exceed the forces due to dead load up to a factor of 1.3. This causes lift-off at the swivel-points.

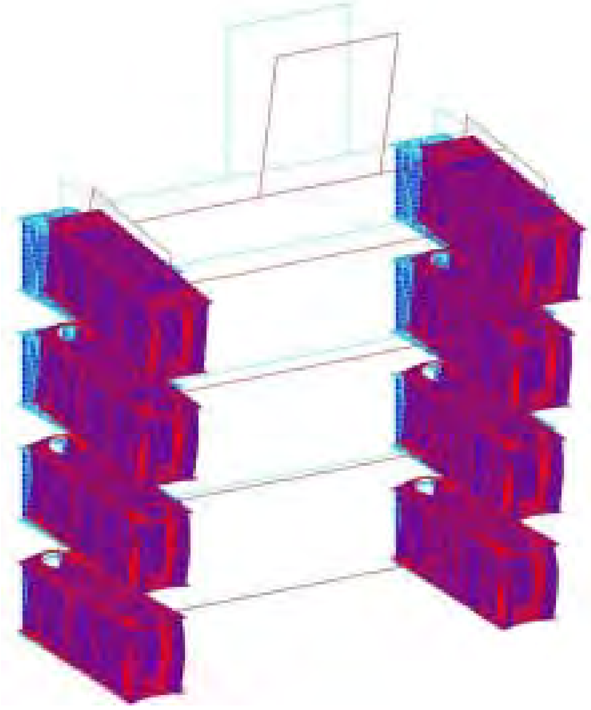

Fig. 3: First Eigenmode of the HF tower (f = 2.90 Hz)

To investigate global stability a non-linear dynamic analysis is done with a simplified model consisting of beam elements with springs for local stiffness. Verification of this model is done by comparison of eigenfrequencies and modes with those of the previous model. For non-linear calculation of lift-off 3D-gap-elements are included at the lowest swivel-points. Vertical and horizontal directions are coupled, this means connection in horizontal direction is only active while the belonging vertical gap is closed.

Artificial time histories belonging to the existing design spectra are generated with a total duration time of 15 sec. To guarantee global stability the earthquake load is multiplied by a factor of 1.1. Response time histories of displacements, accelerations and reaction forces are calculated. Maximum horizontal accelerations are 3.2 m/s^2. No topple over is calculated, but the comparison of the reaction forces show that the non-linear analysis results in larger values than the linear calculation. Figure 4 shows the time history responses of the vertical reaction forces at one of the lowest swivel-points calculated by the non-linear analysis.

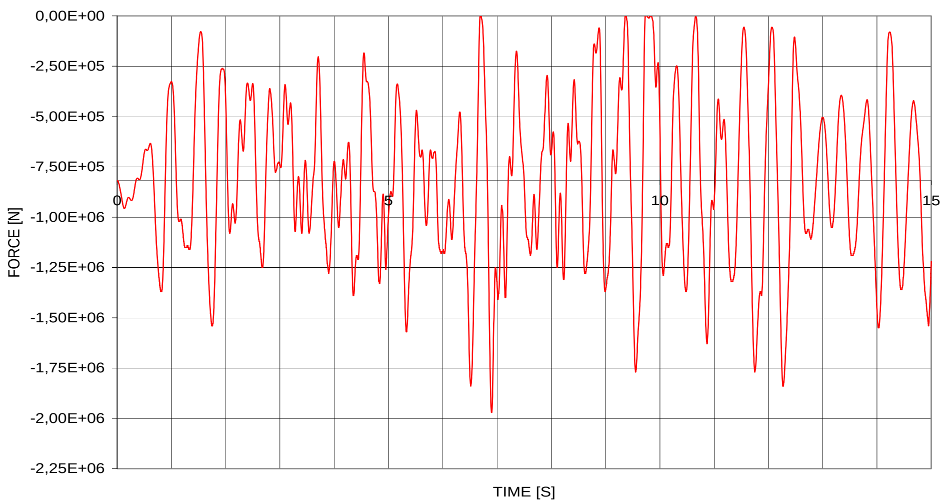

Fig. 4: Time history responses of the vertical reaction forces at swivel-point

The stresses in the risers are analysed for the load case dead weight with earthquake. This is done by applying the maximum occurring reaction forces by way of static loads on a more detailed model of the lowest Riser. The stresses are compared with permissible values according to Eurocode 8 with Eurocode 3, the European rules for earthquake resistance of steel structures. Derived from this, design features in the region of the swivel-points are recommended.

4 END CAP DISK YE1

Each of the both end cap yokes of the CMS detector is comprised of three independent disks with a total mass of about 2300 t. Due to the axial magnetic field the two inner disks must withstand a force of 85 MN and resist the large bending moments induced during operation at the closed detector. Therefore, these disks are 600 mm thick, whereas the outer disk is 250 mm thick. Each disk has 14 m in diameter and is individually supported on a cart which is a large welded steel structure. The carts have been fabricated by Hudong Shipyard in Shanghai. Each cart is equipped with two brace assemblies to keep the disk vertical on the cart. The ends of the braces are fitted with spherical joints to prevent the transfer of bending moments. The other interface between the disk and the cart is designed to act as a hinge.

The critical states for the load case earthquake are during the assembly and the storage in the surface hall, when each single disk with the belonging cart and braces stands without any further horizontal support.

The begin to the dynamic analysis is the derivation of a global linear FE-model including a model of the end cap disk YE1 (Figure 5) with 600 mm thickness and an eccentric heavy mass, springs for the foundation of the surface hall which consider the piles and the mass of the surface hall including all other components.

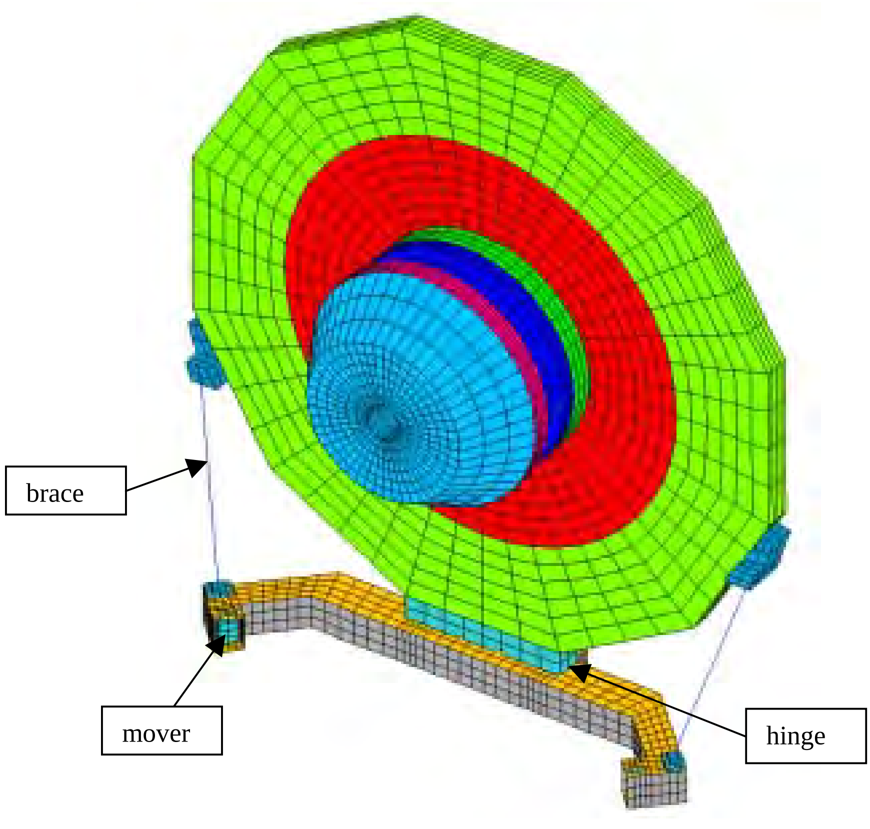

Fig. 5: FE-model of the disk YE1

The first eigenfrequency of the system is approximately f = 0.6 Hz and belongs to the disk on the cart while the following eigenmodes show an influence of the hall with foundation. Displacements, accelerations and element forces due to earthquake loads are calculated with the CQC-method on basis of the design spectra at the foundation of the hall. Displacements and element forces are also calculated for the static load case dead weight. The comparison of the reaction forces at the so-called movers, the 4 bearings of the cart, show that the vertical forces due to earthquake exceed the forces due to dead weight. In the horizontal directions the forces due to earthquake exceed the remaining friction forces between the movers and the floor of the hall.

Non-linear capabilities for lift-off and sliding are added to the existing model. The sliding coefficient is taken from a real assumption to μ = 0.25. Artificial time histories belonging to the design spectra at the foundation of the hall are generated. Response time histories of displacements and forces are calculated.

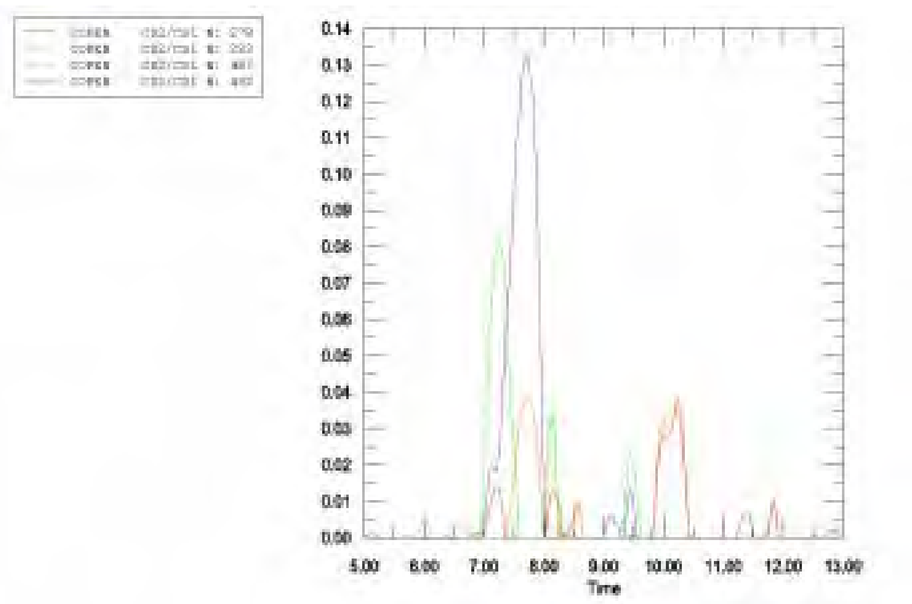

Fig. 6: Time history responses of relative displacements of the gaps

Figure 6 shows the time history responses of relative displacements of the gaps. The relative displacements between the middle of the cart weldment and the centre respectively the top of the disk are much less than the half of the minimal distance of the movers in a horizontal direction. This means no topple over is expected. The calculated sliding distance has a maximum of 550 mm.

Starting from the maximum occurring reaction forces during earthquake stresses are calculated by a static analysis with a more detailed model of the cart. It is incidental that locally stresses exceed the yield point of the steel. Therefore greater deformations can be assumed but global stability is not at risk.

5 CONCLUSIONS

Safety-related components of the CMS detector are analysed for the load case earthquake. Locally, stresses exceed the yield point of the steel, but no topple over is expected with the narrow structures.