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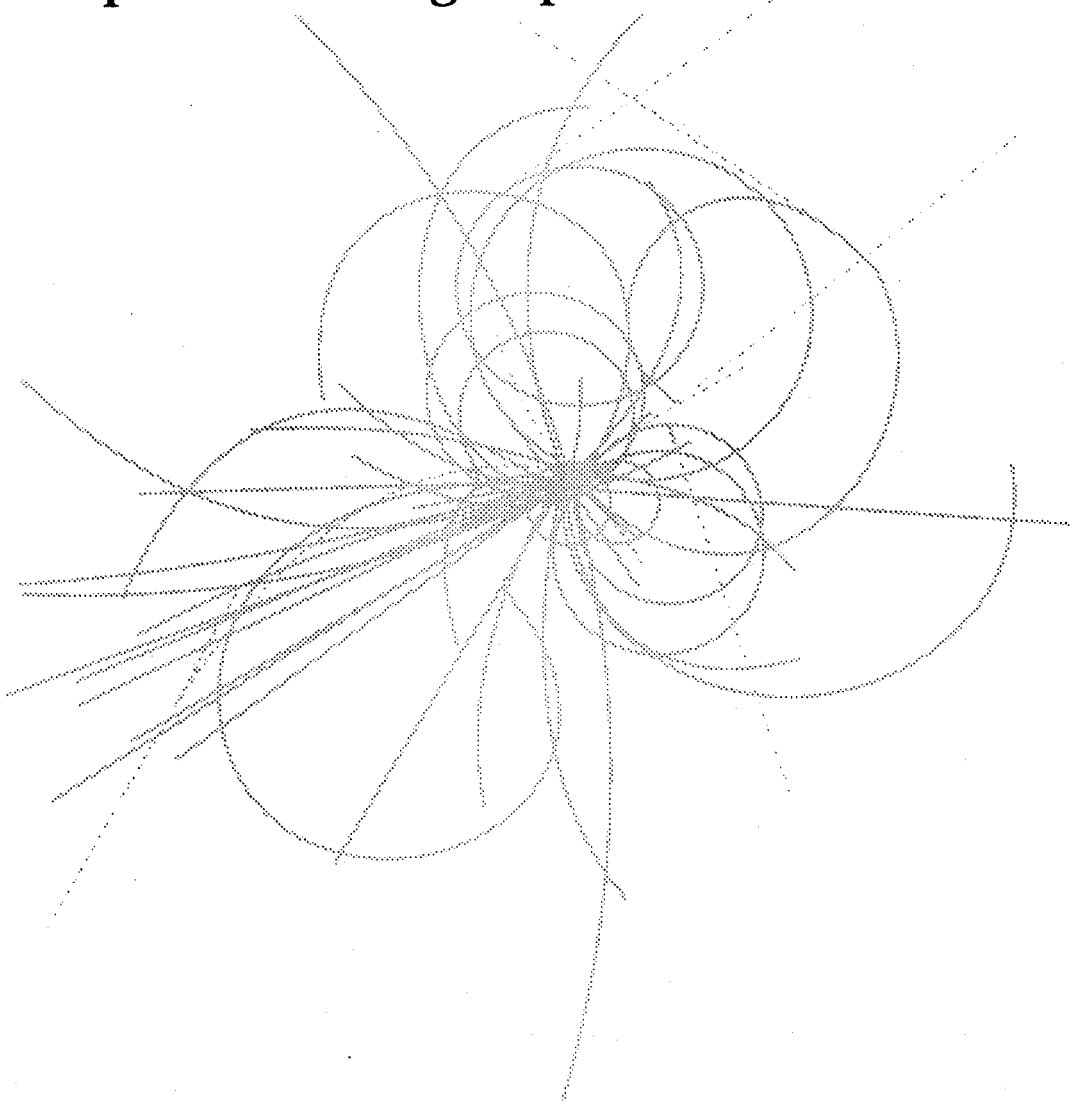

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To be published in *Supercollider 4*

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*Presented at the International Industrial Symposium on the Super Collider, New Orleans, March 4–6, 1992.

†Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC35-89ER40486.

AN ENGINEERING DESIGN STUDY OF DETECTOR DEFORMATION LIMITS IN THE SSC SDC-DETECTOR

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ABSTRACT

The 18,500-metric-ton muon magnet support system (MMSS) is the major component for the large detector proposed by the Solenoidal Detector Collaboration (SDC). The SDC detector requires thick slabs of steel as an absorber. The purpose of this study is to determine and understand the major impact the deflection of the toroid and stress in the connecting bolts have on the magnet design.

INTRODUCTION

The design of the SDC detector called for limited deformation on the magnet steel barrel toroid.[25] Finite element analysis (FEA) is utilized as a simulation tool to obtain acceptable deflection and stress for the magnet barrel toroid. The entire assembly rests on a 10-ft-thick concrete slab which is supported by sub-soil. The steel slabs are first joined together as blocks. The blocks are connected together as an octagonal section. Nineteen octagonal sections are considered as significant and dispersed units for analysis. Each section is joined by pre-tensioning bolts to eliminate gap opening. The magnet structure is modeled in an axisymmetric configuration with the soil modulus applied as an elastic foundation. The ANSYS finite element code is used for the present analysis.** The analysis is not used as a failure analysis tool[4, 5] in structural design but is used early in the muon magnet mechanical design as "a first pass" at the mechanical development cycle.

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**ANSYS is a general-purpose finite-element code developed by Swanson Analysis Systems, Inc.

INTEGRATED MODEL

The muon magnet support system (Figure 1) is composed of five units. The model is based on the conceptual design.[3] The five units are:

Steel Barrel Toroid: An 18,500-metric-ton octagonal steel barrel toroid is modeled with ten sections. A section is made up of four long blocks and four short blocks. All the blocks are 1600 mm thick and made up of ten steel plates. Axial symmetry is used for conservatism and simplicity in the finite element modeling.

Connecting Bolts: The connecting bolts are employed to connect each section and join the blocks to form the section. The stiffness of each pre-tensioning Z- Bolt system is calculated by assuming a 45° shear cone in the clamped steel plate.

Support System: Hydraulic jacks are used for supporting a plate web girder which carries the magnet barrel toroid. Stiffness of the hydraulic jack and the support system vertical stiffness is obtained from a FEA model of the support.[16, 17] The jack is modeled as a compression member only to prevent uplift to the toroid. Coupling is employed in the toroid and girder to account for frictional force.

Concrete Slab: A 3-m-thick slab with effective width of 17.7 m by 50 m is used. The sub-soil properties are modeled as an elastic foundation.

Soil: The soil is recorded as Austin Chalk with an average sub grade modulus of 1000 lb per cubic in.

LOADING CONDITION

Moving load* locations are indicated in Figure 2. The loading is a concentrated loading acting on top of the long block in the bottom toroid. Dead load is computed as 1 G (gravity) for all the units of the integrated model.

BOUNDARY CONDITIONS

Boundary conditions are regarded as symmetrical in $x = 0$ plane and in axial $z = 0$ plane directions. These boundary conditions are rigid because only two translation degrees of freedom are allowed. The boundary conditions in the model required symmetrical loading and therefore moving loads of the same magnitude are acted on both ends simultaneously.

FINITE ELEMENT MODELS FOR ANALYSIS

Model A: The Basic Model. This is the basic model of the muon magnet support system MMSS with the number and location of all the connecting bolts considered in the current toroid design and the current supporting system design.

Model B: Basic Model with 5 times the "C" Bolts. This is an identical model as model A except that all the "C" bolts at the same location are increased by five times.

Model C: Basic Model with 5 times the "C" and "Z" Bolts. This is identical to model B excepted that all the "Z" bolts at the same locations are increased by five times.

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*The moving "forward toroid" load weighing 4000 MT moves into the barrel and induces strain, which is considered as maximum at this particular position.

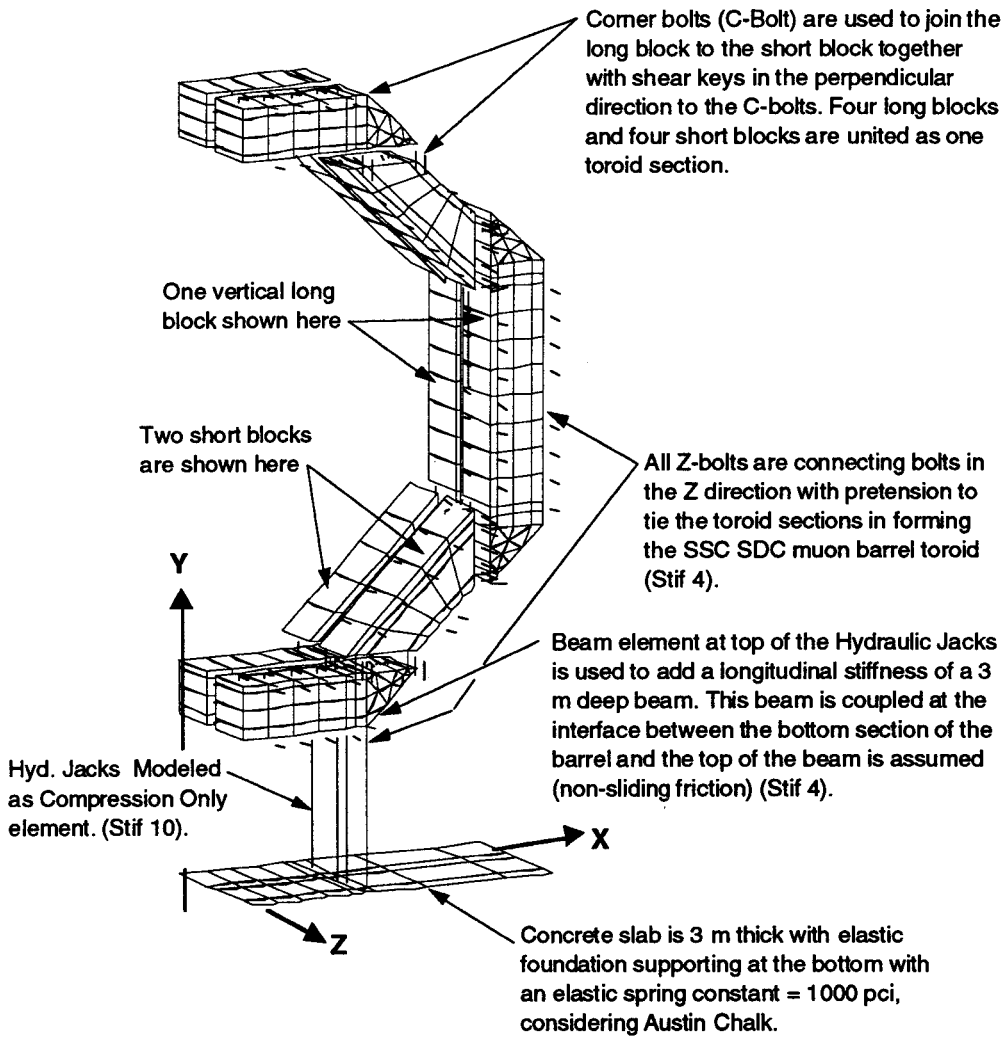


Figure 1. Two sections of MMSS with Gap Size Expanded to Show C-Bolts and Z-Bolts as Connecting Elements.

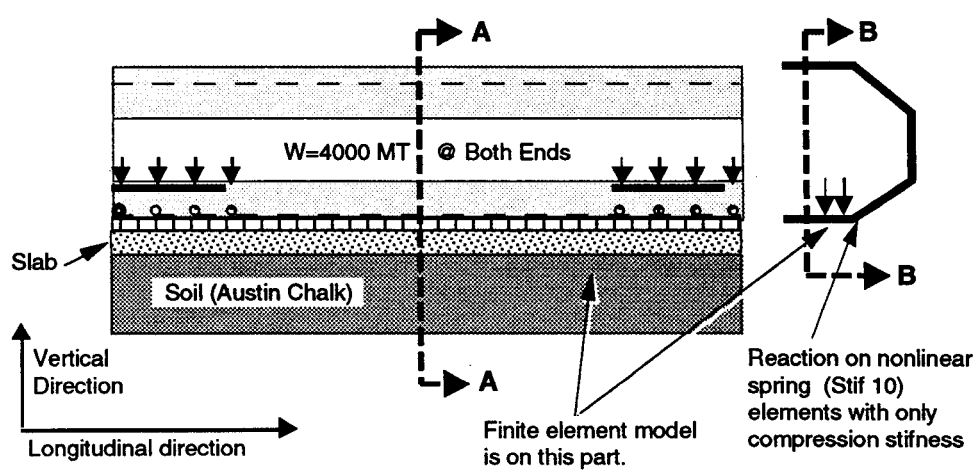


Figure 2. Boundary and Loading Conditions of MMSS.

RESULT OF ANALYSIS

The vertical deflection at the bottom Magnet Barrel Toroid (MBT) is considered as the important analytical result for the following reasons. The moving "forward toroid" load (see Figure 2) acts on this portion of the MBT, consequently producing maximum deflection. The lower portion of the MBT is the interface to the bottom supporting girder. Friction between the girder and the MBT is presumed to be large, and no relative movement between the MBT and the girder would occur. The lower portion of the MBT needs to support the upper portion of the MBT, accounting for more than half of the 18,500 metric-ton dead load. The lower portion of the MBT will be in tension because of the moving load and the elastic foundation action. Excessive separation of the sections will impair the function of the MBT because of the magnet requirement.

This paper is focusing on the MBT deflection and connecting bolt stress (Figures 3–7). The effect of toroid deflection by the soil spring value and the thickness of the slab were reported in SSCL Magnet Engineering Document, Engineering Notes No.: MD-ENG-92-A-001.[24]

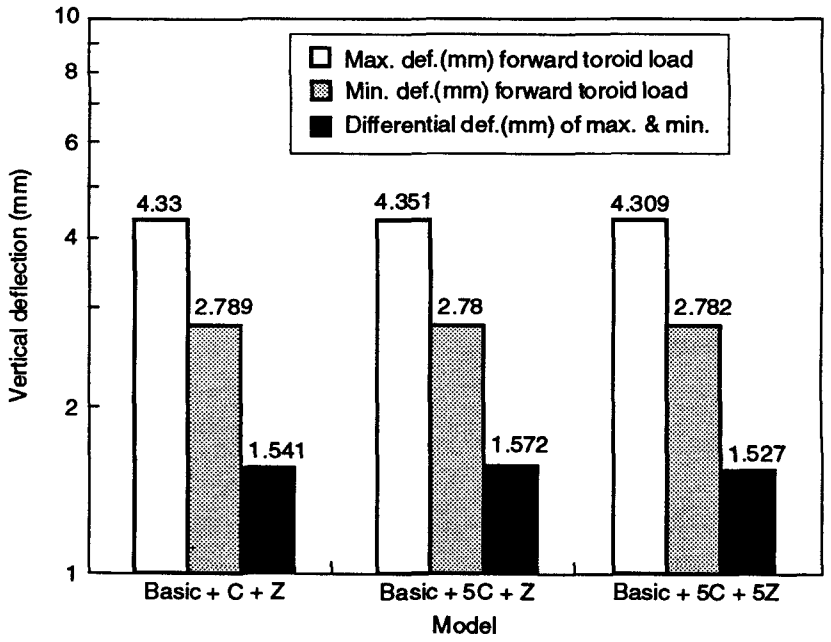
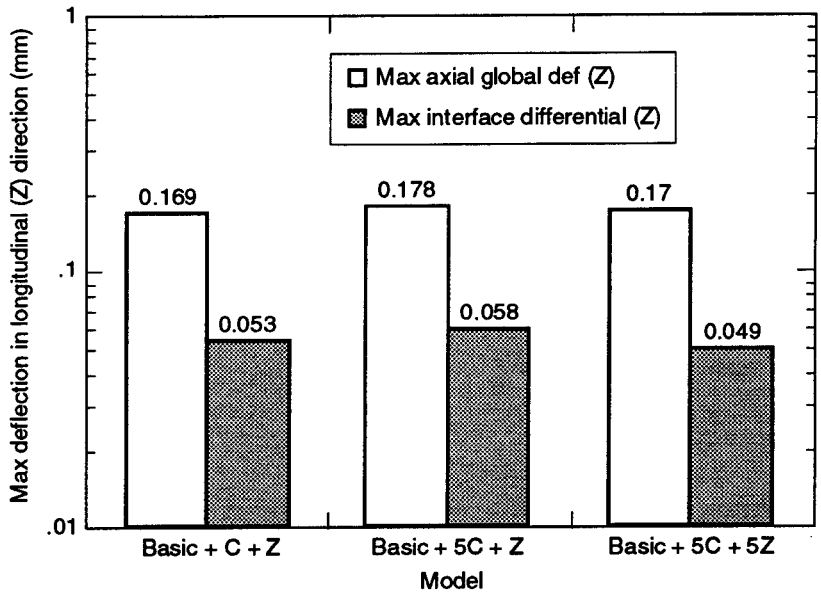


Figure 3. Maximum Vertical Deflection (mm) of the Steel Toroid.



* The def. portion starts from the lowest part of the toroid in the area close to the 4000 M. Ton load.

Figure 4. Maximum Longitudinal Deflection (mm) of the Steel Toroid.

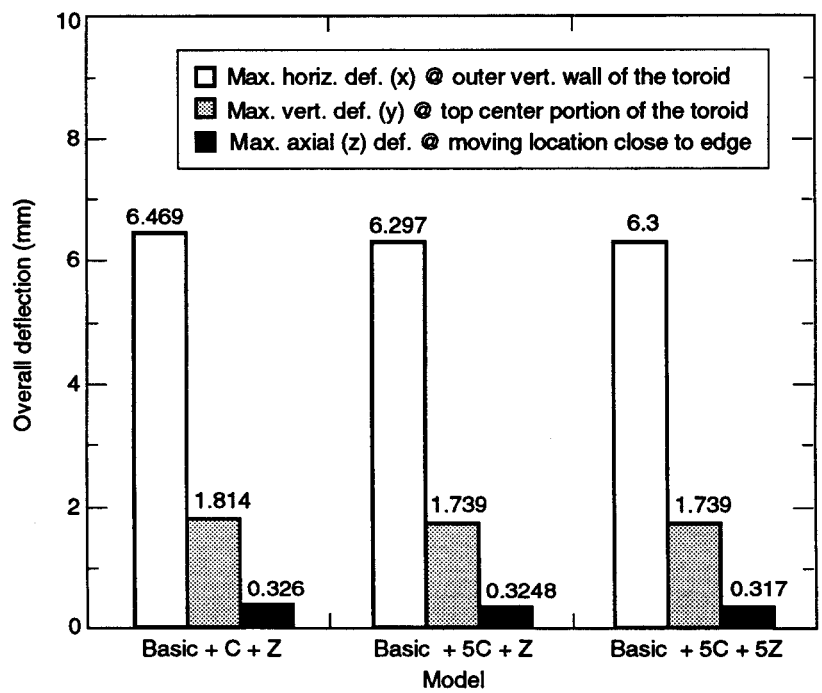


Figure 5. Maximum Overall Deflection (mm) of the Steel Toroid.

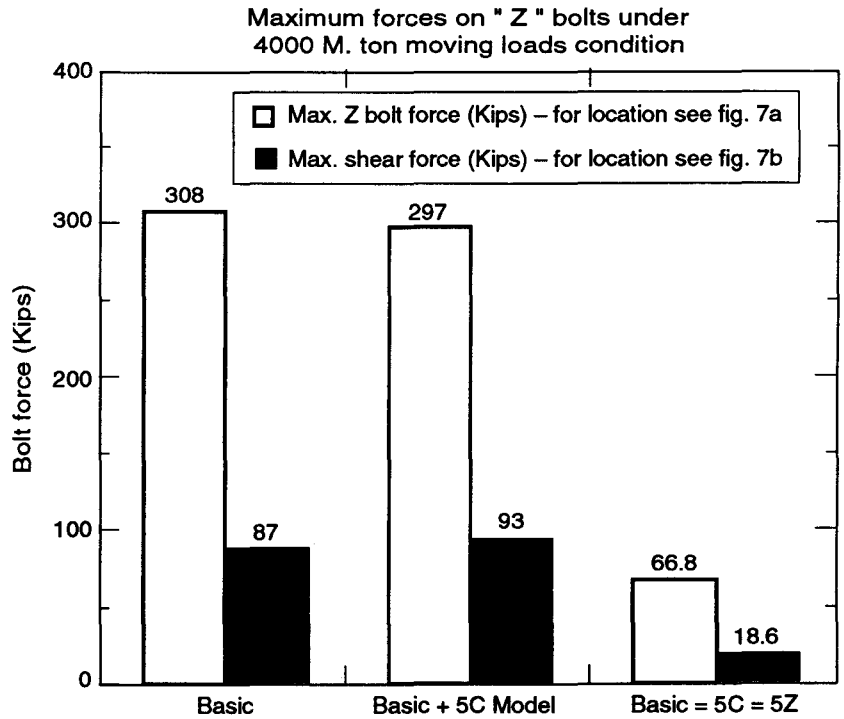


Figure 6. Bolt Force on Bottom Part of Steel Barrel Toroid.

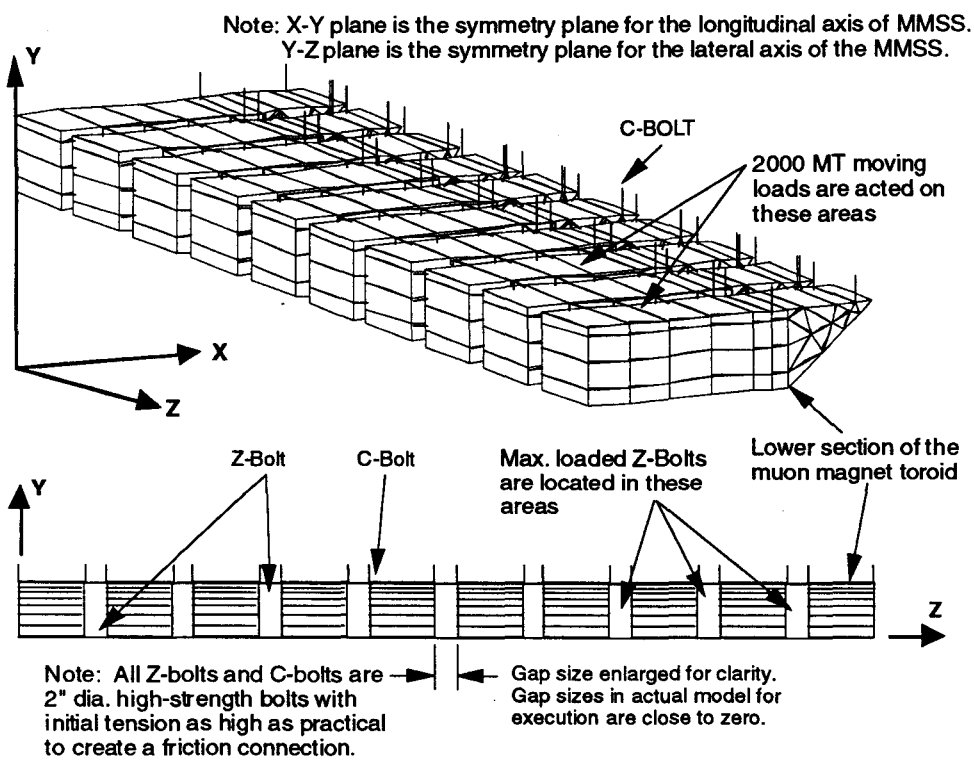


Figure 7. "C" and "Z" Bolt Position on Bottom Part of Steel Barrel Toroid.

DISCUSSIONS

The following conclusions were drawn from this study:

Connecting bolts are not effective in controlling the toroid deflection; stress (308 kips) in the "Z" bolts is excessive (for 2.25-in-diameter bolt, the AISC allowable is 84 kips); high bolt stress and deflection areas are found near the moving load zone; stiffness of the support system and concrete foundation is critical in the design; deflection induced by moving loads is highly localized and has marginal effect on the other parts of the toroid; stress in the toroid and corner bolts is adequate by AISC standard; high stress in the "Z" bolts is induced by the moving loads; deflection on the bottom of the toroid is produced by the moving loads; toroid support needs consideration for distribution of the moving loads; the locations of the toroid support are effective in carrying the body weight of the toroid but ineffective in transferring the moving load to the supports.

RECOMMENDATIONS

As a result of this study, the following recommendations are made for future work: Adding a rigid support is possible directly under the moving load on the toroid to transfer the loads into the supporting girder as much as possible; provide a very rigid loading platform to distribute the moving loads to a larger area of the toroid and support; perform additional finite element analysis in determining the most effective way to reduce the bolt stress and deflection; investigate additional support options such as increasing the stiffness of the support system and of the concrete foundation; investigate other Z connection options such as key ways across the bottom of the toroid, continuous plates, cables and staggered blocks.

CONCLUSION

We have succeeded in understanding the major influence the SDC muon magnet deflection has on the magnet barrel toroid block stiffness and the moving load moment arm, which was measured from the girder supporting point to the moving load acting point. We also discovered a problem with the high connecting Z bolt stress and have recommended several methods to minimize it. The movin "forward toroid" load is the most critical loading condition for the muon barrel toroid. The results show that the critical component of the toroid is the Z connection bolts. Our analysis indicates the Z bolt has little to do with the overall deflection, but is overstressed. We also predict the maximum differential deflection on the magnet barrel toroid is within the specified deflection limit at 3.0 mm.[25] The maximum differential deflection of the muon barrel toroid, as calculated from the present analysis, is about 1.6 mm. Continuous use of FEA as a simulation tool in the advanced design study will reduce engineering changes and achieve a "first pass final" in the final SDC detector mechanical design.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the insightful comments and contributions of the following people: J. Bensinger, J. Cherwinka, R. Gates, G. Snitchler, C.W. Tseng, and T. Thurston.

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