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TARGET AREA STRUCTURAL SUPPORT SYSTEMS DESIGN TO ACHIEVE THE MICRON-LEVEL STABILITY REQUIREMENT OF THE NATIONAL IGNITION FACILITY (NIF)

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ABSTRACT

The Target Area Structural Support (TASS) systems are designed to provide an optically stable support for the target area systems and personnel access platforms for the 192 laser beam configuration. The conceptual design of the TASS systems was an optimum configuration selected from three designs on which performance studies were conducted. The supporting bases for the design selection were the analytical results, operation, and cost effectiveness.

Figure 1. An isometric view of the reinforced concrete building

1.0 Overall description.

This paper presents the design requirements, strategy of design, method of accomplishment, selection justification, and technical issues. For more detail see Ref. 1.

As shown in Figure 1, the TASS systems are housed in a cylindrical steel-reinforced-concrete (RC) building with a 1.8-meter-thick wall, a 1.2-meter-thick dome roof, and a 1.8-meter-thick base mat. The building internal diameter is 30.5 meters, the height is 29.3 meters, and the rise of dome-roof is 4.3 meters. The TASS systems consist of the following elements:

1. An RC floor system cantilevered from the target area building wall.
2. A grid of orthogonal RC ribs filling the cavity of the dome-roof.
3. An RC pedestal resting on the base mat to support the target chamber.
4. Two large aluminum frames to support the turning mirrors and personnel access platforms mounted to the roof and base mat.
5. Groups of small aluminum frames to support turning mirrors and target diagnostics from the bleacher and podium floors.
6. Target chamber/rib joint.

Figure 2 shows an elevation view of the TASS systems conceptual design.

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Figure 2. An elevation view of the TASS systems conceptual design

2.0 Requirements and criteria.

The TASS systems were designed to provide adequate support to the target area systems in order to meet the following requirements:

1. Vibrational stability to maintain the alignment precision for the experiments:
Before each shot, the laser beams must be aligned to the target. After laser, target, and diagnostic alignments has been completed, aiming errors in the optical components may be induced by
 - (1) Ambient random vibration caused by rotating equipment and nearby traffic,
 - (2) Structural resonance to the ambient random vibration,
 - (3) Building distortion caused by wind pressure, and
 - (4) Building deflections caused by solar heat and wind.

An aiming error budget of $50\ \mu\text{m}$ is distributed among the optical components in each laser beam line. To ensure success of the operation, each optical component must maintain its stability by keeping its random vibration below its error budget. The TASS system design is controlled by the final optics and turning mirror error budget of $7\text{-}\mu\text{m}$ translation and $0.7\text{-}\mu\text{rad}$ rotation, respectively.

2. Structural integrity to preclude injury to personnel and damage to optical components caused by earthquakes:

Earthquakes are one of the major natural phenomena hazards to structural integrity. Based on the results of a new site-specific probabilistic seismic hazard assessment for LLNL site, the TASS systems were analyzed to $0.57g$, which bounds the seismic loading of the potential DOE-DP sites under consideration for NIF.

3. Low neutron activated structural material:
To ensure the safety of the personnel in the target area building, the TASS systems have to be made of low neutron activated material. Therefore, the major structural materials are reinforced concrete and aluminum. Steel rebars in the concrete must be protected from neutron activation by a 15-cm concrete cover. Investigation will be performed during Title I design on using graphite composite or aluminum rebars in place of steel rebar to reduce neutron activation.
4. Structure surfaces must be clean and protected to maintain cleanliness levels inside the target area building.

3.0 Design description and method of accomplishment

Among the design requirements, the stability requirement is the most stringent and controls the design. It is expected that when the structures satisfy the vibrational stability requirement, they will satisfy the structural integrity requirement as well. The strategy for the design of the TASS systems is to provide a stiff support aided by passive damping treatment, and to isolate any known sources of vibration. This plan is detailed below (See Ref. 1 for detail):

1. Considering the design strategy, physical constraints, and cost factor, the following three configurations were selected to maximize the use of available space inside the target area building:
 - a. Annular Ring Model represents a floor system composed of two annular rings cantilevered from the cylindrical wall to provide four floors.
 - b. Column/Beam Model represents a combination of columns and beams to support the target diagnostic floor and mirror floors.

- c. Aluminum Space Frame Model represents an aluminum space frame isolated from the target area building roof and wall.
2. The following finite element analyses were performed to determine the adequacy of the designs:
 - a. Power Spectral Density (PSD) analyses to calculate the vibration responses.
 - b. Thermal analyses to estimate the temperature distribution.
 - c. Static analyses to calculate the solar heat and wind deflections.
 - d. Response Spectrum analyses to estimate the seismic responses.
 - e. Static analyses to calculate the gravity loads.

The analytical process used to verify the stability and structural integrity requirements are presented in the Figures 3 and 4.

Figure 3. Analytical process to verify the stability requirements.

3. Define realistic design parameters for the finite element analyses.
4. Select structural materials of high material damping values.
5. Obtain realistic material damping values by testing.
6. Apply passive damping treatment to dampen the vibration in the support systems.

Figure 4. Analytical process to verify the structural integrity requirements

4.0 Performance studies and design configuration selection

The performance comparison focuses on the modal behavior and the random vibration responses. Ref. 1 describes the finite element analyses in detail.

4.1 TASS system models performance comparison

The random vibration comparison is dependent on the structure's natural modes of vibration. The importance of each mode depends on the participating mass that is excited in that mode. The mode shapes of the column/beam model indicate that the dynamic behavior of the structure is driven by the chamber; consequently, the fundamental frequencies are reduced. Such a frequency content change can lead to an increase in the dynamic response. On the other hand, tied to the chamber, the annular ring configuration results in no frequency shift because the mass and stiffness in the annular rings are much higher than those in the chamber. However, the annular rings pull the chamber away from the pedestal. This may induce high dynamic loads at the chamber/pedestal interface. In this case, the chamber/rib joints should be designed not to transmit vertical motion or loads to mitigate this effect.

The RMS translation and rotation at the locations where optical components are supported were evaluated. As a whole, the annular ring model tied to the chamber

has small random vibration translations (below 1.19 microns). This is lower than the other configurations. The lateral support from the annular rings to the chamber significantly improves the lateral dynamic stability of the chamber and is an important design feature.

4.2 Justification for the configuration selection

Based on the requirements and criteria, the annular ring model is the most favorable TASS systems configuration. The justification for this selection is presented below:

- It costs less than the aluminum space frame while meeting the performance requirements.
- Its translation responses are uniformly lower than those in the other models.
- Its random vibration responses are very much below the design requirement; indicating a possible optimization of rib array and downsizing the cross-sections of the ribs.
- It provides four floors for personnel access, supporting capability, and operation spaces.
- It provides lateral support to the target chamber and still behaves like a simple integrated structure without changing its frequency content.
- Some turning mirrors are close to the cantilevered floors, and can be supported by them. The random vibration responses of the floors are small, which makes them reasonable for turning mirror supports.
- It is a reinforced-concrete structure, which has a higher damping effect than an aluminum space frame.
- It has minimum space conflict with the beam path, allowing freedom for future alteration in the beam path layout.
- It leaves a clear floor on the base mat for accessibility during operation and for direct air flow passage; the other options clutter the base mat.
- It is a simple, symmetric, well-behaved, and well-understood structure; capturing a high percentage of the participating mass in a few dominant models, unlike the complicated behavior shown in the column/beam modes.

4.3 Changes made to the conceptual configuration for cost reduction

The following changes were made to the original design to reduce cost:

- The number of the ribs was reduced from 18 to 16 per annular ring.
- Every other rib was trimmed by 6 feet in length, because the rib arrays were too closely spaced at the free end.
- The uniform 3-foot thickness was tapered to 1.5 foot thickness at the free end.
- Some turning mirrors are supported on the bleacher floor and podium floor because the random vibration responses on the annular rings are very small, less than one mm. Besides, the turning mirrors are closer to the floors than to the dome-ribs.

5.0 Performance of the conceptual design

A more detailed computer model was developed to simulate design configuration. The analytical processes to verify the stability and structural integrity requirements were performed. The vibrational responses are below the requirements. To identify the amplification of motions from the TASS systems to the mirrors, a roof mirror support frame was analyzed applying the in-structure translation PSD at the center dome-rib as input. The resulting total vibrational motion at the bottom of aluminum frame was also verified.

The solar heat penetrates only about 1/3 of the roof thickness. The temperature in the roof rises a maximum of 13.3°C during an elapsed time of 2 hours between alignment and firing the shot. The resulting vertical and lateral deformations on the dome-ribs exceed the design requirements. Consequently, thermal insulation on the roof is required.

The calculated wind deflections are 5 microns in the lateral direction and 2.5 microns in the vertical direction. These deflections are combined with the other motions for stability verification. The combined responses are still below the design requirements provided that the roof is thermally insulated.

The seismic stresses in the TASS systems are well below the allowable stress levels. The connection between the chamber and ribs have passive damped joints, which will reduce the seismic loads and vibrational motion. However, these combined responses do not account for any effects from rotational ground motion, flexible base mat, or soil-structure interaction.

6.0 Technical issues, options, and assessment of alternatives

Preliminary analytical effort has been performed in an attempt to better understand the structural behavior to date. The results show that the current design satisfies the design requirements. There are some technical issues to be studied in detail to ensure a thorough understanding of and to improve upon the current design configuration. The issues include:

1. Reducing lateral seismic loads in the chamber/floor joints:
The computer model proves that a rigid, non-damped truss element at the joint is adequate. But a specially designed damped joint in place of this truss will dissipate vibrational energy, provide lateral stability, reduce the seismic loads in the ribs and floors; and reduce the random vibration to the optical components. More detail on the damped joint design is presented in Ref. 1.

2. Investigating the structural responses from the flexible base mat, soil-structure interaction, and rotational ground motion:

The analyses were conducted assuming a rigid and fixed base mat. The structural responses from the flexibility of the base mat and soil foundation may be estimated by using sophisticated computer codes. In general, the flexibility of the base mat leads to an increase of structural responses; the soil-structure interaction results in a reduction of structural responses. These analyses are highly technical and will be performed during the Title I design phase.

Estimation of the micro level vibrational responses of a structure from the rotation of the base mat is a unique problem to NIF program. To simplify the analytical process, the responses from the rotation of the base mat may be estimated by a scale factor applied to the responses from the translation of the base mat. A factor of 1.1 was developed. However, such factor has to be verified and validated before it can be applied.

3. Measuring the true material damping values for realistic representation of structural behavior:
The damping effect test results indicated a significant increase in dynamic responses. In the design analyses, 2% and 0.5 % were used for RC and aluminum structures, respectfully, to increase confidence in the computer simulations. Accurate

damping values must be known to obtain realistic responses. Measured damping values close to what were used in the analyses could increase confidence in the estimated responses. One method of obtaining the material damping values is to excite the structural material and to measure its vibration-time history. If a single mode is excited, material damping may be calculated from the decrement time history. The difficulty in measuring the material damping values for a thick reinforced concrete wall is that a large amount of input energy is required. Forcing devices currently available for studies conducted at LLNL do not apply enough energy to sufficiently excite the thick concrete walls (i.e., produce several cycles of motion). Other options for measuring material damping values are discussed in Ref. 1.

4. Reducing thermal distortion by providing thermal insulation to the roof.

The thermal distortion effect of the building on the chamber exceeded the translation design requirements of the final optics. Providing thermal insulation on the roof can reduce the temperature profile and thermal penetration in the roof. The effectiveness of an insulation can be identified by thermal analyses. Another option is to provide thermal barrier over the roof. A well-designed shroud can effectively reduce the thermal distortion and the wind deflection of the building and TASS systems.

7.0 Summary

The current annular ring TASS system is the optimum choice among the three options investigated. Analyses were conducted to estimate the static and dynamic responses. The resulting motion and stresses are within the design requirements and material capacities. Passive damping treatment will be added to the mirror support structures to reduce random vibration motion.

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8.0 Reference 1

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