

# Optimization and Analysis of Modular Cantilever using Finite Element Approach

**Introduction:** Overhead modular cantilevers are basically designed to support the assembly of overhead power transmission wires (i.e. catenary (1000/1200 kgf tension), contact (1000/1200 kgf tension), and droppers to transfer the overall bending, transverse and vertical load to the mast via insulators (Fig. 1). There are few characteristics that quintessential cantilever should satisfy such as light weight and robust enough to support the current carrying assembly with trains speed 200 kmph (minimum) [1]. Now days along with above mentioned properties railway sector is also focusing on aesthetic, ease in maintenance, ease in transportation, ease in handling and other related issues. In this work, simulation model was established to study structural topology optimization to devise the novel design of overhead modular cantilever to eliminate ancillary components by efficient use of material which ultimately saves both cost and material.



Figure 1. 3D schematic of overhead modular cantilever with key components.

**Computational Methods:** Model describes optimal distribution of slab with dimension of 3.5 meters by 1.2 meters with the thickness of 0.18 meters acting as a cantilever beam with the load of 1.2kN applied at its one end. Clearly initial model was oversized as stresses are unevenly distributed and hence not making effective use of the material. For optimization minimization of total strain energy set as an objective function along with the minimization of total mass criteria. The detailed flow of simulation is shown in fig. 2 in which solid mechanics represents structural properties of model while optimization interface forcing constraints, variables and objective.



Figure 2. Physics interface and optimization with simulation work-flow.

The SIMP (Solid Isotropic Material with Penalization) method used to accomplish the significantly binary topology checkboard pattern with stress tensor mentioned below, with artificial density  $\rho_{\text{auxiliary}}$  and Young's modulus  $E_0$  [2].

$$E(x) = \rho_{\text{auxiliary}}(x)^p E_0, \quad 0 \leq x \leq 1$$

Penalty factor  $p$  which makes intermediate density provides less stiffness compared to what they cost in weight with value greater than or equal to one. Basically attempt was to minimize the amount of material without violating the strain energy constraint. MMA optimization solver was used due to its capability to generate quick and reliable optimized topology with limited number of iterations for model with successively finer meshes.



Figure 3. Initial geometry under optimization study.

To regularize such intrinsically mesh-size dependent problem, solution was made mesh independent using the independent dimensionless penalty equation as shown below, where  $R_0$  is initial mesh size and  $R_{\text{max}}$  is current mesh size at given level.

$$\frac{R_0 R_{\text{max}}}{A} \int_V \left( \frac{\sigma_{xx}^2 + \sigma_{yy}^2}{A} \right)^p dV$$

This penalty term is for worst possible solution, on the order of 1. It was necessary to balance it against the real strain energy. To achieve this initial system with homogeneous density was solved for structural analysis using reference strain energy value equal to 1. After initial solution the value of reference strain energy was updated with normalized strain energy value of 64.731 J/m.

**Results:** Plot in fig. 4 shows the stiffness distribution for optimized solution. The resulted design was for the selected parameters such as material used and loading conditions. White area represents material where as the black areas represents void. Useful optimized design should be essentially in checkboard from unless composite material used for manufacturing. The study was performed with the regularization weight of  $q = 0.1$  to get sharp result without altering the topology.



Figure 4. Optimized shape used to create new cantilever design. Optimized model using Start Model (Top), modified 3D CAD model of derived concept (middle), generated modular concept using previous knowledge and specifications (Bottom).

With optimization there was 72-3% reduction in mass of the system compared to the initial geometry (Fig.3) used under study without violating the specifications. 3D model created using optimized study later subjected to structural analysis and eigenfrequency analysis.

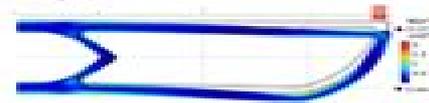


Figure 5. Equivalent stress, von Mises stress.

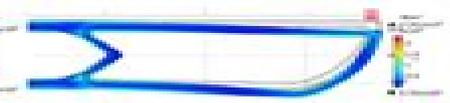


Figure 6. Equivalent stress, Tresca stress.

In fig. 5 and fig.6, the equivalent stresses of the types 'von Mises' and 'Tresca' are shown, respectively. The type of material used for the structure is structural steel has yield strength,  $\sigma_y = 250\text{MPa}$  (minimum), which is much higher compare to the observed maximum induced equivalent stress (2.32MPa). This leads to the space where we can further modify the design.

Eigenfrequency analysis was performed to study its modal responses for the frequencies up to 100Hz. Force exerted by pantograph on register arm via contact wire was analyzed with equation  $55 = 0.0048 v^2$ , where  $v$  is speed of the train [3]. Fig. 7 and fig. 8 shows the first six mode shapes and the frequency shift in eigenmodes respectively.



Figure 7. Six first eigenmode shapes.

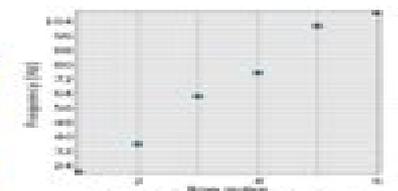


Figure 8. Six first eigenfrequencies.

**Conclusions:** A simulation model was established to optimize the conventional overhead modular cantilever using topology optimization technique. Started with general block subjected to the practical loading conditions, conventional model was modified to enhance overall functionality with less components. Topology optimized model was used to create new design concept and later subjected to the structural analysis (strength and modes) to verify optimized results.

## References:

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2. M.P. Bendsoe, "Optimization shape design as a material distribution problem", Structural Optimization, vol. 1, pp. 193-202, 1989.
3. Cho Y. "Numerical simulation of the dynamic responses of railway overhead contact lines to a moving pantograph, considering a nonlinear dropper", J.Sound Vib. 2008;315:435-454.

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