Stress-Strain Analysis of a Parking System's Grid

Lucas Amaral Costa
Mechanical Engineering Department
Universidade Federal de Minas Gerais
Belo Horizonte, Brazil
llucasac@ufmg.br

Alessandro Corrêa Victorino
Professor of the Mechanical Engineering Department
Universidade Federal de Minas Gerais
Belo Horizonte, Brazil
victorino@demec.ufmg.br

***Abstract* — As there's a rapid increase in the fleet of vehicles in urban areas the problem of finding parking spaces for these vehicles arises. One possible solution to the parking problem is found in the verticalization of the spaces. Therefore, a previous discussion published by this research group launched a state-of-the-art device designed to park two vehicles in the space necessary to park only one. A patent request for the device was deposited under the registration number BR1020170118142. The launched parking system had many attributes that characterized it as an invention, as for example its elevating platform which is constituted by a hanging grid working as a second-class lever. The present discussion shows the development and optimization process of this parking system's grid which was achieved by means of stress-strain analysis and CAD/CAM technics. On a first stage, the grid's dimensions were estimated. Secondly, the load condition of the structure was calculated with aid of the software MASTAN2®. On a third stage, the obtained results were used in the manual stress-strain analysis of the grid. On a fourth stage, all the prior steps were iteratively reperformed converging to the grid's optimal dimensions to support the load conditions. On a fifth stage, the results were refined with the Finite Element Method (FEM). A virtual prototype and a detailed project were developed in the software SOLIDWORKS® v. 2018. The attained structure presented optimal resistance to deformation at minimal weight being an effective solution to the elevating platform of the parking system.**

Keywords — Parking system, CAD/CAM technics, stress-strain analysis, grid.

I. INTRODUCTION

According to a study [1] published by the Polytechnic School of the University of São Paulo (Poli), which evaluated data from the real state market since the year 1930, 25% of the whole built area in the city São Paulo is used as parking lot. In other words, from each 4 m^2 of the built area, 1 m^2 is used as parking lot. This urban problem requires a solution since this parking area could be more efficiently occupied, e.g., as commercial, residential and recreation areas. One possible solution to the problem is in the verticalization of the use of the parking space. Thus, parking systems have already been proposed. The patents US 5110250A of 12/18/1990, PI 9906103-1A of 11/18/1999 and PI 0002843-6A of 6/14/2000 present devices that allow parking at least two vehicles in the space required to park only one. They have a smart design, and a drive generally formed by electro-mechanical or electro-hydraulic assemblies. It lacks on the literature a device that reunites on the same system, many of the good qualities individually found in each of these devices, with other state-of-the-art attributes. Therefore, a previous study [2] published by this research group presented the innovative parking system on Fig. 1. It's constituted of a lift platform working as a second-class lever, which drive is formed by a movable pulley and an electric hoist. A patent request was deposited under the number BR1020170118142. One innovative characteristic that is interesting to notice is its lift platform which has only three fixities instead of four, i.e., one of its corners is hanging.

Figure 1. Parking duplicator view with focus to the elevating platform which is hanging

Thus, this hanging lift platform requires proper dimensioning. It is formed by a structural steel grid, i.e., a steel frame composed of beams that sustain all the strain of the platform. The present study approaches the stress-strain analysis of the grid, which was performed by means of manual analytical methods and CAD/CAM technics, aiming to select the grid's beam.

II. MATERIALS AND METHODS

In order to select the square beam that constitutes the grid, determining the optimal cross-section dimensions and wall thickness of the beam, a series of iterative steps were performed. First, coherent dimensions and thickness were guessed. These values were then used in the iterative process. Based on the obtained results, new and better values for the dimensions and wall thickness of the beam were chosen and the steps were reperformed until optimal values were found, i.e., the ones that ensure maximum load at minimum weight of steel. Thus, the analytical analysis of the grid was systematically performed as follows: A. Estimation of the Grid's Dimensions; B. Strain Calculus on the Software MASTAN2®; C. Stress-

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Strain Analysis; D. Reperform of the Steps A to D with the New Guess; and E. Finite Element Analysis.

A. Estimation of the Grid's Dimensions

According to its applicability on the lifting platform of the parking system, the grid's architecture was established, i.e., HSS-Shape structural steel with a square cross-section. Then, the beam's wall thickness and cross-section width were determined selecting the beam shape that would constitute the whole grid frame of the elevating platform. The optimal beam is the one that presents the smallest dimensions and good mechanical properties. A structural steel supplier's catalog [3] was used to select the beam. First, an initial guess was made for the beam fixing coherent width and thickness. As the next steps were conducted, a sequence of improving approximate solutions derived from these initially chosen values, finally converging to the optimal beam width and wall thickness available on the supplier's catalog.

B. Strain Calculus on the Software MASTAN2®

In order to calculate the distributed load on the grid, it's important to compute the weight of the own steel structure that constitutes the grid, besides the weights of the vehicle to be elevated and additional elements of the lifting platform. Once the beam was selected in the previous step, the mass per unit of length of the chosen beam and consequently the weight of the beams were known and so used in the present step. Considering the distributed load acting on it, the grid was modeled on the software MASTAN2®, thus the shear force, bending and twisting moments were computed. Fig. 2 shows the diagram of the shear stress acting on the grid in the y-direction. These values were calculated on the software MASTAN2® and used on the next step, the stress-strain analysis.

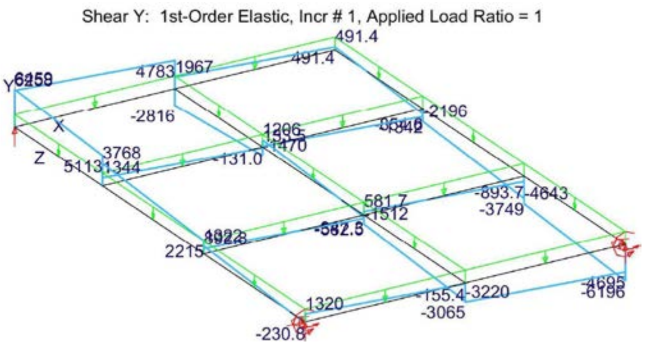

Figure 2. Shear force diagram

C. Stress-Strain Analysis

Considering the beam supporting the major load, the problem under consideration, i.e., the grid under the presented load condition, has its shear stress, bending and torsion resistance modulus, which allow the evaluation if the beam securely resists the strain. As in [4], the results obtained on the previous step were used to determine these three values for the problem. Thus, the shear stress was calculated according to (1), where τ_c is the shear stress, F is the shear force and A is the area of the beam's cross-section.

$$\tau_c = \frac{F}{A} \tag{1}$$

The bending resistance modulus was calculated according to (2), where W_x is the bending resistance module, M_f is the bending moment and $\overline{\sigma}_f$ is the permissible bending stress.

$$W_x = \frac{M_f}{\overline{\sigma}_f} \tag{2}$$

The torsion resistance modulus of the problem was calculated according to (3), where W_t is the torsion resistance module, M_t is the torsion moment and $\overline{\tau}_t$ is the permissible torsion stress.

$$W_t = \frac{M_t}{\overline{\tau}_t} \tag{3}$$

These values must be lower than the respective ones for the beam: the material's permissible shear stress, the beam's bending resistance modulus, and the beam's torsion resistance modulus - more details on Table I in the section "III. RESULTS AND DISCUSSIONS". The beam resists the load conditions if the problem values calculated through (1), (2) and (3) are lower than the respective beam's values. If the condition isn't satisfied for any of these values, the beam doesn't resist the load conditions and thus will be rejected. Besides this manual analytical method, the beam was also analyzed with the Finite Element Method [5] on this step.

D. Reperform of the Steps A to D with the New Guess

If the beam estimated on step A is rejected on step C, another beam with higher dimensions, i.e., larger thickness and/or width, is chosen. Thus, the steps A to D are iteratively reperformed until a beam that successfully supports the load conditions is selected.

E. Finite Element Analysis

Once the optimal beam is selected, a Finite Element Analysis (FEA) is performed according to [5]. The FEA is performed not only on the individual beams but also on the mounted frame, as shown in Fig. 3, where a virtual prototype of the grid was developed on the software SOLIDWORKS® for the simulations to take place.

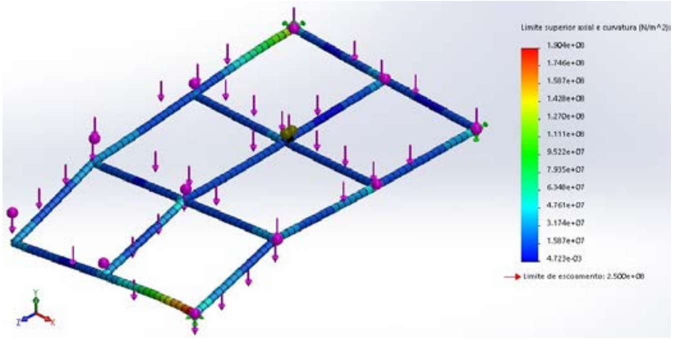

Figure 3. FEA on SOLIDWORKS® Simulation

III. Results and Discussions

The present discussion aimed the stress-strain analysis of a parking system's grid designed to lift vehicles up to 2,000 Kg. The grid is the main mechanical element designed to support any load on the elevating platform. Fig. 4 presents a virtual prototype of the grid, which was extensively evaluated through manual analytical and computational methods.

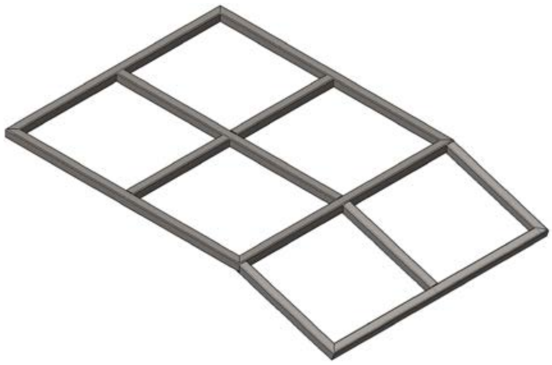

Figure 4. Elevating platform's grid

In the mechanical dimensioning of materials, the parts are designed to support the load conditions with security. Hence, the dimensions of the parts are calculated so that only elastic deformation occurs. No plastic deformation can take place. Thus, the work strain must be lower than the permissible strain of the material. The permissible strain is the strain that allows safe operation and it is calculated as the material's yield strain divided per a security factor. Table I shows these results for the stress-strain analysis conducted on the section "C. Stress-Strain Analysis". As the values on column "Problem" are all lower than the respective ones on column "Beam", i.e., the strain originated from the load conditions on the grid problem is lower the strain that the steel structure mounted with the beams can support. For this reason, only elastic deformation will occur on the grid, no plastic deformation will take place.

TABLE I. DIMENSIONING PARAMETERS

Parameter	***Problem***[a]	***Beam***[b]
Shear Stress	3.55 N/mm^2	63.74 N/mm^2
Bending Resistance Modulus	51.40 cm^3	54.20 cm^3
Torsion Resistance Modulus	50.33 cm^3	81.70 cm^3

a. Calculated with the equations on the section "C. Stress-Strain Analysis".

b. *Data extracted and edited from [3] and [6].*

It's interesting to notice that the bending moment was the limiting strain on this project, i.e., it was the strain that actually determined the wall thickness of the selected beam, once the bending resistance modulus is on its threshold while the shear stress and the torsion resistance modulus values in the column "Problem" aren't so close to the respective ones in the column "Beam". Fig. 5 shows important dimensions of the grid, all properly dimensioned as aforementioned. The beam selected to build the grid is the 100x100 mm with a wall thickness of 5,0 mm. Its material is the ABNT 1045 cold rolled steel (ASTM A36). The grid weights 337.73 Kg.

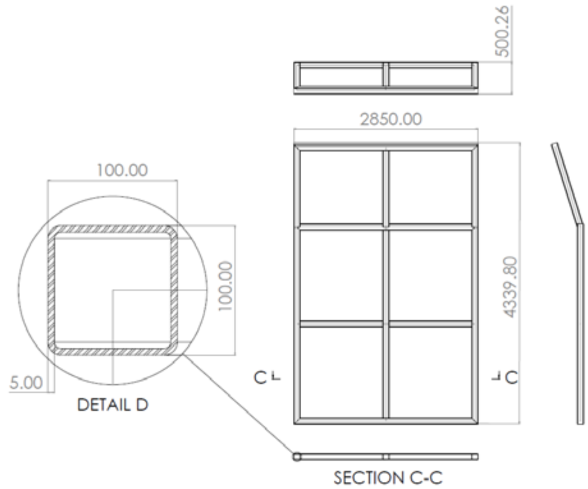

Figure 5. Grid's important dimensions

In order to ensure safety, besides the executed stress-strain analysis, national standards as ABNT, NR-10, NR-12, NR-17 and international standards as ISO 9000 and ISO 14000 will be met by the project making it a good and safe solution available on the market. Comparing the designed structure to similar equipment that is commercialized or is in the state of the art, it is an interesting solution considering its applicability on the parking system, possessing the markable characteristic of having only three fixities instead of four, i.e., one of its corners is hanging as seen on Fig. 1. [7] and [8] present analogous studies where the stress-strain analysis of platforms was conducted. The platforms of both discussions are constituted of sandwich plate, the one in [7] is made of steel while the one in [8] is made of composite material. The use of composite materials associated with a sandwich plate system (SPS) can smartly allow maximum equivalent stress at minimum weight, as this is an important objective to be attained in this type of project, like the one in the present discussion.

IV. Conclusion

The stress-strain analysis of the grid was efficiently conducted with the main objective of attaining maximal equivalent stress at minimum weight. The study leads to the following conclusions. The designed architecture is an efficient choice for the parking system's grid, being capable to lift a vehicle that weighs 5.92 times the weight of its steel structure. The bending moment is the limiting strain. Once the structure is dimensioned to resist the bending moment, it will resist to all other strains. The analytical methods and the FEA Analysis effectively selected the beam with the cross-section of 100x100 mm with a wall thickness of 5,0 mm to build the grid. The beam's material is the ABNT 1045 cold rolled steel.

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