Structural analysis of a food truck subjected to impact loads

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Abstract: The article focuses on the evaluation of impact loads to the structural design of a conventional food truck through static lateral collision tests with dynamic and static study based on several requirements and regulations of the international standard (ECER95) where force determine of impact generated laterally in a totally inelastic. The physical variables that interact in this phenomenon with the variation of mass, velocity and determine their real impact are analyzed with mathematical equations. The validation of the combined loads was developed by CAE software applying the LRFD method complying with Regulation No. 95 of the Economic Commission for Europe (UNECE) of the United Nations with a collision between the stationary conventional food truck and a vehicle, which impacts it at 50 km/h where the deformations under United Nations Regulations No. 95 and No. 66 are determined, guaranteeing the occupants survival.

1. INTRODUCTION

Around the world, is noted the presence of the so-called "Food Trucks", like mobile vehicles of the sale of food, which are generally mobile structures that are adapted inside with equipment that helps with the food preparation [1]. However, being an emerging local production trade in urban areas, there are no entities that can help with the regulation and registration of these, due to the growing evolution around 2008, from which there is a big competition for hoarding urban spaces, offering varieties of food [2], thus creating profitable new trends that create new business models for automotive companies, which offer several motorized models or trailer type that fit the type of food to be sold.

The manufacturer or adaptation of automobiles is carried out in an artisanal way for its proper functioning, the few industries that take the risk are based on the "Technical Standard of Automotive Vehicles, Buses Bodyworks" [3], because this is the closest and similar in the requirements for "Food Trucks", and in other similar documents that allow the manufacturer to make a design and carry out respective tests that allow validating this design through a finite element analysis [4, 5]. This reason is established as a need to test a typical model of "Food Truck" and analyze the structure against different static and dynamic loads [6] that may occur in an unconventional way in its daily operation [7] as established by the corresponding standards [8, 9, 10], in which tests are settled down on the structure, such as Lateral impact test in which the structure, that is kept at rest, is impacted laterally by a motor vehicle at a speed of 50 km/h and a flip test in which the structure is overturned, turning to one side resting on its own wheel and falling to a depth of eight hundred millimeters.

This article has 4 sections, including the Introduction. Section 2 describes the food truck structure design considerations and the tests developed based on Ecuadorian and international regulations to
validate the design. Section 3 describes the results obtained from the tests performed. Finally, the conclusions are shown in section 4.

2. MECHANICAL DESIGN

It is necessary to consider that the final product must have adequate geometry and materials in order to comply with safety aspects that are necessary to minimize the possible effects accidents effects [11, 12]. Similarly, it is necessary to take into account the adequate materials for its construction and the respective quality standards for the material manufacture, as a fundamental point that will provide a higher resistance index of the structure likened to the tests to be carried out [13,14].

2.1. Types of structures for Food Trucks

There are several models, some commercial and others of artisan manufacture, but within the national market, there are two types of structures, truck type and trailer type "figure 1a". In this study, it will analyze a trailer structure "figure 1b" because it is the most accessible option for public at large, mainly because its mobilization requires only a modification to an existing car allowing savings in the purchase of a new car engine.

2.2. Normative

The bus structures and the Food Trucks are very similar so that the studies applied will be similar too [15], as well as their shape, materials, and types of loads. Taking NA ISO 3833: 2007 as a starting point where general requirements are established for the design, manufacture, and assembly of bus bodyworks, which will be designed to withstand the stresses generated by load combinations, the NTEINEN 1323 standard: 2009 establishes two methods: Method ASD (Allowable strength Design) and the LRFD Method (Load resistance factor design), in these methods it is established that the deformation of the structure must not exceed 1/240 of its total length. The strength of the structure is determined by one of the methods contemplated in regulation 66 of the United Nations [8]. For modeling, the parameters are required ("figure 2.a" and "figure 2.b") Stipulated in Resolution No. STHV-016 [11].
2.3. Materials and modeling

According to research carried out on regulations and works with similar structures [12,15] carried out within Ecuador, it can be deduced that the materials most used in similar structures are those shown in "Table 1".

| Element          | Regular tube | Quality standard | Manufacturing standard |
|------------------|--------------|------------------|------------------------|
| Framer “Figure. 3a” | 100 x 50 x 3 | ASTM A 500 Gr. A | NTEINEN 2415           |
| Floor “Figure. 3b”  | 50 x 50 x 4  |                  |                        |
| Walls “Figure. 3c”  | 50 x 50 x 1.5 |                  |                        |
| Roof “Figure. 3c”   | 50 x 50 x 1.5 |                  |                        |

According to the norms NA ISO 3833: 2007 and the parameters are shown in "figure 2", stipulated in the resolution STHV-016 [10] modeling of the structure in Siemens NX software is performed, it is divided into its main elements, which are shown in figure. 3a, the floor is shown in "figure. 3b", roof and walls shown in "figure. 3c", the entire structure has a mass of 332 kg.

2.4. Study conditions

The dynamic and static study of Food Truck is performed based on several requirements of national (NA ISO 3833: 2007 and STHU-0.16 UIO) and international (ECER95) regulations, which managed safety conditions against different loads. These involve the application of various forces that can generate various failures at the structural level, putting at risk the occupants’ integrity.

Impact force based on the Impulse theory and motion quantity, it is studied the case that the designed component is at rest and is impacted at 50km/h (ECER95) laterally generating a totally inelastic shock. For the analysis of these phenomena it is necessary to identify the factors that act in each of them, where "Vo1" is the initial speed of the Food Truck (0km/h), "Vo2" is the initial speed of the mobile barrier (50km / h), "T" is the shock contact time (20ms), "m1" is the mass of the Food Truck (1181.49kg), "m2" corresponds to the mass of the mobile barrier (1500kg), "P" is the amount of motion, "I" represents the variation of "P", "F" is the force, "VR" is the resulting speed, "Vf1" corresponds to the final speed of the Food Truck and "Vf2" is the final speed of the mobile barrier.

To obtain the force of impact, it is started from the principle of motion quantity conservation [16] defined in equation (1), equation (2) shows all the physical terms that interact in this phenomenon. Equation (3) implies the velocity resulting from an inelastic shock where the masses must be added, finally, the equations (4), (5) and (6) link the variation of the motion with the mass, speed for later define the value of the impact force in equation (7).

\[ P_1 = P_2 \]  \hspace{1cm} (1)

\[ m_1 \cdot Vo_1 + m_2 \cdot Vo_2 = m_1 \cdot Vf_1 + m_2 \cdot Vf_2 \]  \hspace{1cm} (2)
VR = \frac{m_1 v_0 + m_2 v_2}{m_1 + m_2} \quad (3)

I = \Delta P = P_f - P_o \quad (4)

P = mV \quad (5)

I = \Delta P = mV_f - mV_o \quad (6)

F = \frac{\Delta P}{\Delta t} \quad (7)

Based on the previous equations, it is determined that the impact force is equal to F = 458.9 kN. This force would be exercised directly and distributed according to the number of elements that make up the structure in that area. The appropriate size to mesh the different elements that form the Food Truck is defined by directly relating the degrees of freedom with this, in order to find the appropriate dependence to reduce the error product of nodal displacement [15, 16]. Table 2 defines the size of the mesh in millimeters as a function of the degrees of freedom, the error, and displacement generated by each of these different sizes, it is determined that the best combination facilitates the digital process and with the least possible error in a square mesh of 15 mm.

Table 2. Validation of mesh.

| Mesh Size [mm] | Degrees of freedom | Displacement [mm] | Error [%] |
|---------------|--------------------|-------------------|-----------|
| 5             | 25 927 500 000     | -1.747            | -4.82     |
| 15            | 7 842 000 000      | -1.667            | -4.6      |
| 25            | 150 000 000        | -2.175            | 30.5      |
| 50            | 50 500 000         | -1.349            | -38.0     |

According to this information, the definition of the finite element method (8) is applied, this is defined as a matrix ("ε" is the deformation matrix, "α" is the nodal displacement vector and "H" are the coordinates of the system) that links the nodes and reduces the system in their nodal junctions (9), from these mathematical arrangements the different variables that validate the system are obtained. [15, 16]

\[
[\varepsilon] = [H] [\alpha] \quad (8)
\]

\[
\begin{bmatrix}
\varepsilon_1 \\
\varepsilon_2
\end{bmatrix} =
\begin{bmatrix}
H_{11} & H_{12} \\
H_{21} & H_{22}
\end{bmatrix}
\begin{bmatrix}
\alpha_1 \\
\alpha_2
\end{bmatrix} \quad (9)
\]

2.5. **Static and dynamic loads Study**

The analysis of static and dynamic loads is developed by software based on the Impact force data and the mesh size required for this case, applying the norm NA ISO 3833: 2007 defined by the LRFD method and the regulation No 95 of the Economic Commission for Europe (UNECE) of the United Nations. These regulations establish the need to carry out a study of combined loads on different parts of the structure for static analysis and two tests (turning and lateral impact) for dynamic analysis.

Table 3. Types of loads required for the LRFD method.

| Type of load    | Nomenclature | Value [N] |
|----------------|--------------|-----------|
| Dead weight    | M            | 8829.00   |
| Live weight    | V            | 2749.60   |
| Spin load      | G            | 2091.02   |
| Braking load   | F            | 4721.12   |
| Drag load      | Raf          | 3105.02   |
| Acceleration load | Ab         | 4721.12   |
For the static analysis, it is necessary to define the loads that act on a Food Truck, and similar characteristics to a Food Truck, in table 3 each one of the loads necessary for the study of the LRFD method are detailed. The loads shown are applied in combination to different parts of a Food Truck unit, each combination of loads requires its mathematical analysis [17]. Nine different cases of study are represented the whole. Table 4 shows the case, the equation that defines it and the area of the unit where the load acts.

Table 4. Cases of analysis according to the LRFD method

| Cases          | Areas of application              | Equation                         | Value [kN] |
|----------------|-----------------------------------|----------------------------------|------------|
| Case 1         | Floor                             | 1.4M+V                           | 15,109     |
| Case 2         | Floor and side                    | 1.2M+1.6V+0.5G                   | 16,038     |
| Case 3         | Floor and side                    | 1.2M+0.5V+1.6G                   | 15,315     |
| Case 4         | Floor, front and internal supports | 1.2M+1.6F+0.8Raf                | 20,632     |
| Case 5         | Floor, front and internal supports | 1.2M+0.4V+0.5F+1.3Raf            | 18,091     |
| Case 6         | Floor and internal supports       | 1.2M+1.5Ab+0.5V                  | 19,051     |
| Case 7         | Floor and back                    | 0.9M-1.3Raf                      | 3,909      |
| Case 8         | Floor and front                   | 0.9M+1.3Raf                      | 11,982     |
| Case 9         | Roof                              | 0.5 (load of the floor and frame) | 4,414      |

The dynamic study is regulated by the norm No. 95 of the United Nations (CEPE) and involves two cases, each one of them involves a specific procedure, then, each of them is detailed: Case 10 (Turning) This particular case is managed by the regulation No. 66 Uniform provisions concerning the approval of large passenger vehicles with regard to the strength of their superstructure, which implies that the structure must turn around on its wheel and fall from a height equal to eight hundred millimeters. "Figure 4" details the parameters of regulation No. 66 for the flip test, in the same way, the nomenclature used in this figure is defined.

Case 11 (Lateral Impact) This case is managed by regulation No. 95, looking for the homologation of vehicles for the protection of its occupants in the event of a side collision. For this, the conditions required by the method and explained in the calculation of the impact force are used.

![Figure 4. An explanatory chart on the flip test](image_url)

![Figure 5. Case 5 deformation study; a) Application of combined loads on the structure b) Deformation obtained.](image_url)
3. RESULTS

According to the data established in the static analysis, a study of each case takes place using CAE software. In "figure 5.a" it shows the application of the combined loads corresponding to case 5 on the roof, floor and walls, in the "Figure 5.b" graphically shows the effort and deformation marked in red by the change of strong tones to determine the points with greater deformation and the blue or light blue tones for the points with the minimum change with regard to its initial state.

Table 5 summarizes the results obtained in each case, verifying that each of these does not exceed the limit value established by the normative NA ISO 3833: 2007 exhibiting values that on average do not reach 65% of the maximum allowed value. These data reveal that the structure is reliable and will suffer deformations that do not affect the area of survival of the occupants.

| Cases | Permissible deformation [mm] | Deformation obtained [mm] | Percentage value |
|-------|-----------------------------|---------------------------|------------------|
| Case 1 | 19.6                        | 14.4                      | 73.45%           |
| Case 2 | 19.6                        | 13.3                      | 67.85%           |
| Case 3 | 19.6                        | 14.5                      | 73.97%           |
| Case 4 | 19.6                        | 16.8                      | 85.71%           |
| Case 5 | 19.6                        | 12.8                      | 65.30%           |
| Case 6 | 19.6                        | 14.6                      | 74.485%          |
| Case 7 | 19.6                        | 7.83                      | 39.94%           |
| Case 8 | 19.6                        | 3.72                      | 18.97%           |
| Case 9 | 70                          | 37.80                     | 54%              |

Case 10 obtains the effort to which this structure is subjected when turned over, under the conditions established in Regulation No. 66. In "Figure 6.a" the simulation of the phenomenon can be seen by computer. From this study, it is obtained that the effort generated in this case is 0.228 MPa being very small in comparison with the last tensile strength of the materials that is 400 MPa and is also minimal in comparison with the yield strength.

Figure 6. a) Flipping test b) Side impact test

In case 11 the impact is simulated according to the norm No 95 obtaining a shock of 150 ms, in the "Figure 6.b" the development of the collision between the stationary Food Truck and a vehicle that impacts it at 50 km/h is appreciated. Of this case, it is highlighted that the impacted part moves 546mm, where the limit according to the norm is 600mm.

4. CONCLUSIONS

The stipulated Food Truck design complies with the NA ISO 3833: 2007 normative and the Regulation of the United Nations No 95 and No 66 ensuring that the proposed equipment is safe, it will have deformations lower than 65% the limit value stipulated in the standards and in the case of collisions or turns, it is ensured that the occupants or, failing that, their spaces of survival will not be
affected in any way, as long as the loads are similar to each of the studies carried out.

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