# UNIVERSITY OF CRAIOVA

# FACULTY OF MECHANICS


**Doctorate Thesis**
Summary

CONTRIBUTIONS TO THE STUDY OF RESISTANCE MECHANICAL STRUCTURES USED FOR CARS STORAGE


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Thesis Presentation

The origins os the automatatic parking systems date back in 1905s, in Paris, which at the time had the most cars in the urban environment. It has been understood that it is a crowded car park, it has sought a solution to store them so that the architecture of the city will remain intact. Automatic parking systems, also known as automated garages, car parks, multi-storey car park, robotic, or simply buildings, the solution is as simple as it is effective: the cars are stacked in racks on many levels. This solution allows, for instance that 20 cars will occupy the same space as four if they would have been parked under normal conditions. Automatic parking for vehicles is based on a technology similar to that used for mechanical handling and retrieval of documents. The driver leaves the car in a module, and it is then transported to a parking lot by a robot trolley. For the driver, the process of parking is reduced to leaving the vehicle inside a module.

Congestion during peak periods, can lead to good minutes on hold due to luggage or due to passengers from the vehicles but not because of the parking stand. This loading blocks entry or exit cars and is not available for celelelate motor vehicles. If the vehicles recovery is faster in a parking lot or in a conventional car park that depends on the layout and number of openings. There are two types of automated parking systems, depending on how they carry the machine from the entrance to the parking lot: horizontal or vertical platforms, elevators. In both cases, the process is very similar, only one thing makes the differences: the movemenet of the machine by the time it reaches the desired space (laterally or vertically). Once positioned on the ramp, the driver switches off the engine, assures the car by using the parking brake and he exits the car. While he does all these, all the sensors start to determine the size of the car and to examine its overall shape.

A solution that is much applied is the massive use of steel. Steel technologies in parking structures on several floors becomes increasingly more prevalent in Europe, proving advantageous solution, which not only reduces production time, but also allows building various architectural forms.

Advantages of multi-storey car park that use elevator:
-suitable for both parking in public areas and private;
-elevator is used in housing blocks, shopping centres and offices;
-the safety is assured by the use of parking areas and by the use of safety sensors;
-access to and exit from the parking Bay is fast, secure and convenient;
-lift system is the most efficient in terms of space necessary for installation;
-operation of the system is monitored by a computer;
-the system operates with very low levels of noise and vibration;
-maintenance costs are reduced to a minimum;
-cost for a parking space is low

*Classification of the multi-storey car park:*

a. Depending on the construction height
b. Depending on the degree of complexity
c. Depending on the setting mode
d. Depending on the number of parking spaces
e. Depending on the degree of automation

*Advantages and disadvantages to develop multi-storey car park:*

a. Advantages to develop multi-storey car park from constructive point of view:
-fully enclosed space-protection from rain, sun, wind;
-requires a small space for installation, which can be found more easily in city centres;
-are the most effective in the use of the existing space, exceeding the efficiency to develop classics parkings;

-can fit much better into the architecture of city centres;
-their facades can simulate both old buildings as well as modern ones;
-cars are parked at very small distances some towards other compared to regular car parks because we don't need the doors to be opened;
-automated parking systems can be built both at the surface and in depth depending on the space available in a city;
-parked cars are much safer because there is no public access to the parked cars;
-parking lot damage such as scratches and dents are almost inexistent;
-drivers and passengers no longer have to walk through parking lots or garages;
-driving around in the search of a parking space is eliminated, thus reducing the emissions of particulate matter;
-access of persons with disabilities is enhanced;
-electric lighting is not needed (low cost of electricity);
-computerized control, intelligent, easy to operate;
-any potential problem is reported on line at a central station;
-the car is positioned towards the exit in such a way as to be able to drive directly;
-there is no need for searching the vehicle into a crowded parking lot;

b. Advantages of multi-storey car park from the finacial point of view:

-reduce the cost of land. On the theory that an automatic structure uses about half of the land, the cost savings can range from 100% to 400 or 500%, depending on the value of adjacent property;
-these cars drives can operate without staff or with a single assistant;
-have a payback period of depreciation greatly reduced;
-low cost maintenance;
-it reduces the surface constructed;

c. Benefits of bunk parks taking into consideration the environment:

-reduce the distance travelled within the garage that is equal to emission reductions, such as carbon monoxide, nitrates and nitrogen oxides that are considered major problems in most urban places (up to 35% less $CO_2$ and 44% less fuel);
-environmental problems in terms of noise level, but just as important, particularly in the area of densely developed, are light and noise created by vehicles moving inside a conventional garage;

*Disadvantages to develop multi-storey car parkings:*

-high cost of construction but is offset with the ground surface and can build in neighbourhoods with limited spaces areas but requires a large number of parking spaces;
-somewhat confusing to users;
-it is not recommended for a large volume of transfer from peak hours;
-fear of breakdown;
-requires maintenance contract with the supplier;

***Presenting the multi-storey car parkings that have less height***

- Multi-storey car park systems with 9 parking lots (fig.1)

- Multi-storey car park systems with 4 parking lots (fig. 2)

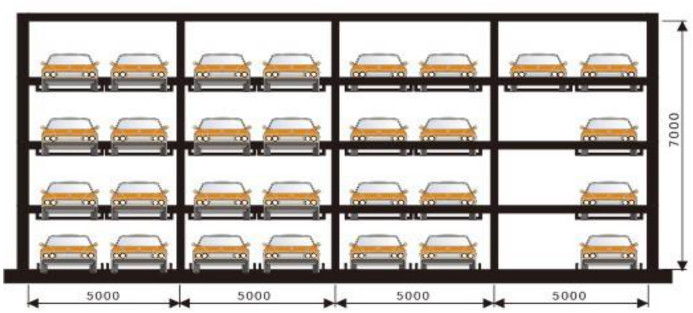


Fig.1 The way that the cars are arranged and spaced between

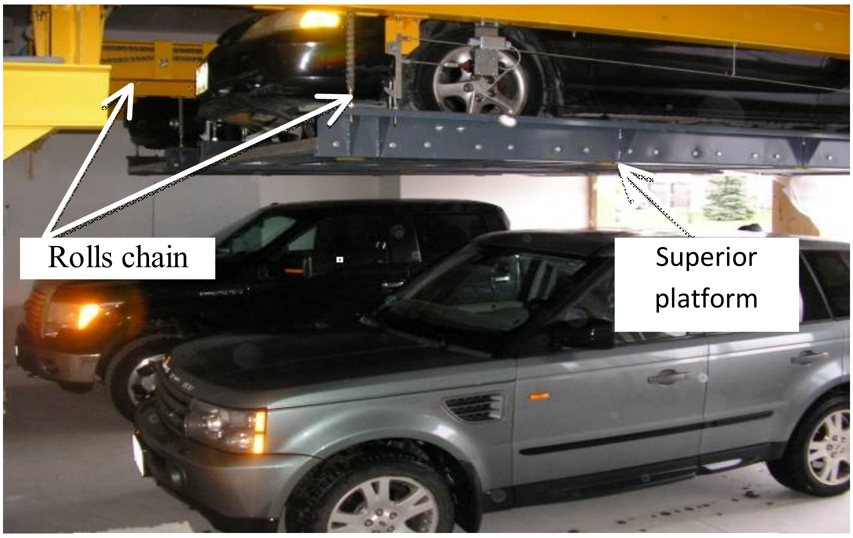



Fig.2 Multi-storey car park with elevator for 4 parking lots

- Multi-storey car park underground but with less depth

- Multi-storey car park underground but with less depth  that has a hydraulic functioning (fig.)


Fig.3 Multi-storey car park  with 2 parking lots with hydraulic functioning

## SYSTEMS  OPERATING PROBLEMS FOR THE MULTI-STOREY CAR PARKS

1. Noise generator. The facility is built with a generator for those moments when power is interrupted.
2. In the case of simultaneously car parks we  have to wait for a large period of time (the time a car is parked is for 2.5 minutes).
3. High noise coming form the engines when boarding on the platform .
4. In the case of a breakdown of the elevator all the vehicles remain locked untill the damage is fixed
5. In case of an earthquake all the cars can be damaged or they can remain blocked in the parking lot.
6. Case Study for the risk - laden structure. There may be cases when all the parking spaces are occupied on one side of the structure which can lead to eccentric loading.
7. Case study at the starting and stopping of the system - if the vehicle is parked or take-over.

8. Case study  at the start, namely stopping the system in an emergency-this event occurs in situations where the broken cinematic chain
9. Case study of safety systems at the time of breaking the chain.

***In Chapter 2  ,, Multi-Storey car parks – mechanical and cinematic schemes"*** we present the schemes, both mechanical and cinematic ones for  different types of those parkings.

*Mechanical schemes of a multi-storey car park  with low height.  (fig. 4)*

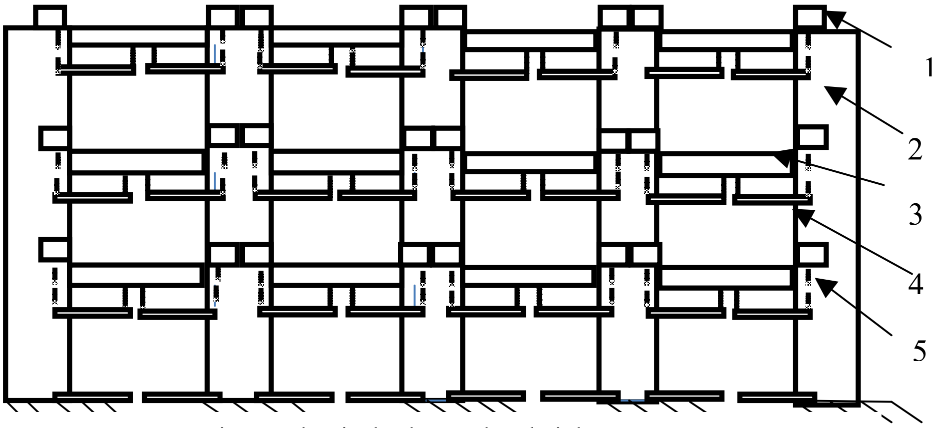



Fig. Mechanical scheme- low height system
1-cross beam;     2-pillon; 3-horizontal beam ;  4-car platform;  5-chain ( cable)

*Cinematic schemes of a multi-storey car park  with low height (fig.5)*

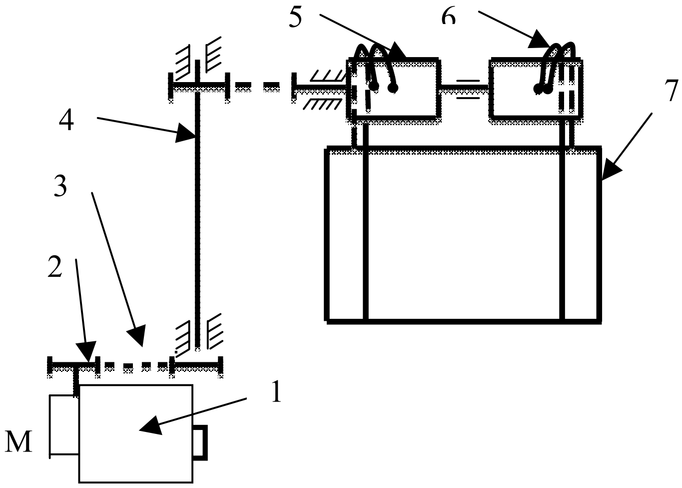



Fig. 5 Cinematic scheme
1-electric motor;  2-pinion;  3-chain; 4-axel; 5-buffler;
6-cable;  7- car platform

Mechanical schemes of a simple multi-storey car park (fig. 6)

Cinematic schemes of a simple multi-storey car park (fig. 7)

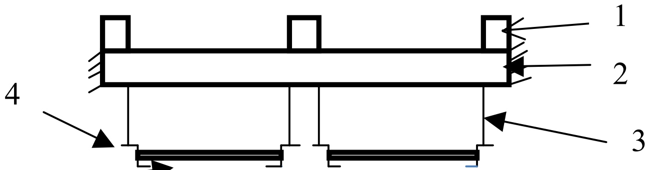



Fig.6 Mechanical schemes  1-longitudinal beam ; 2 – cro ss beam ; 3-rolls chain ; 4-platform beam
5-traversele platformei

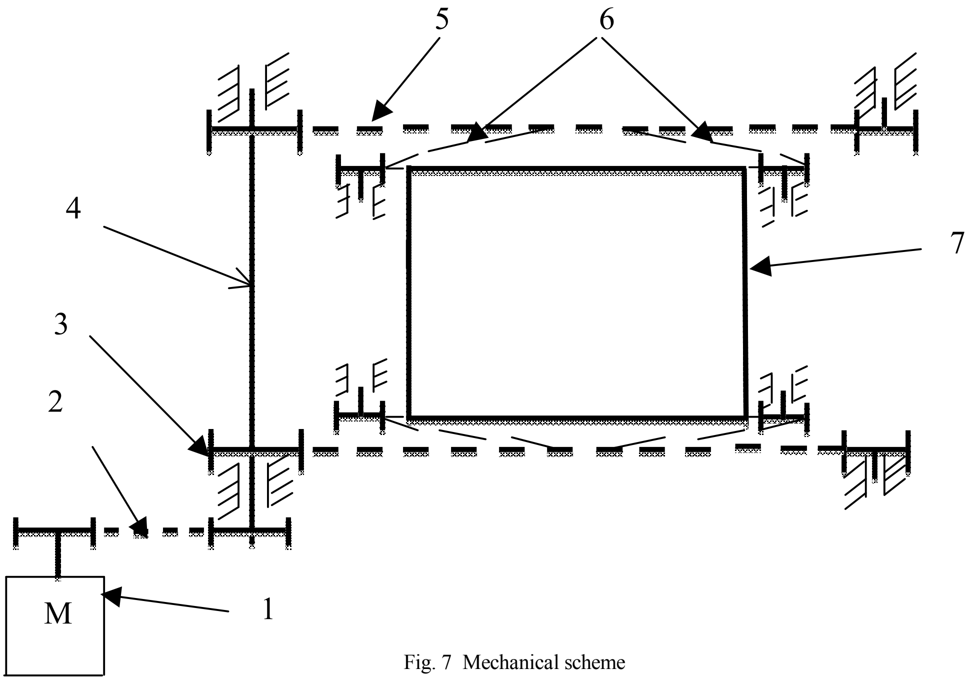



Fig. 7 Mechanical scheme
1-electric motor; 2-main chain; 3-cogwheel; 4-axel; 5 – cinematic chain; 6-force chain; 7-auto platform

***Chapter 3, „Mechanical efforts and tensions in the structure of a multi-storey car parks "*** presents all types of resistance ecuations for 3 types of those kinds of parking systems :

- loading systems with 2 forces (fig. 8)

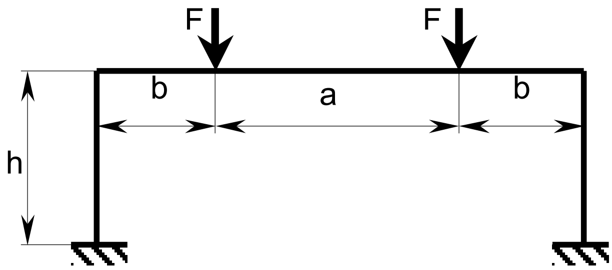



Fig. 8 Loading systems with 2 forces

- Loading systems with 4 forces (fig. 9)

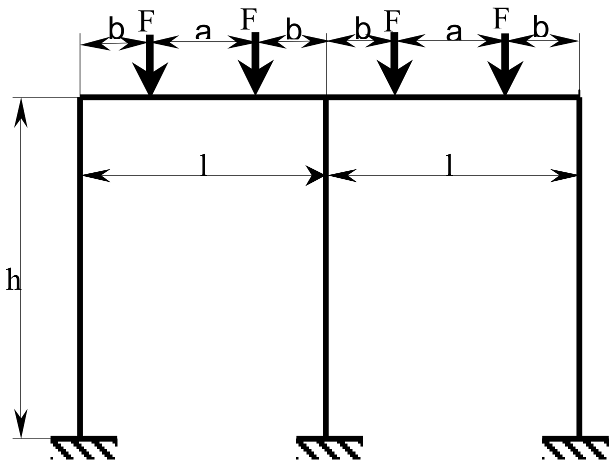



Fig. 9 Loading systems with 4 forces

- Loading systems with 2 multi level forces (fig. 10)

We consider for the variables a,b,h,F the next values :

a=152cm; b=40cm;
h=(145cm, 147cm, 168cm, 172cm);
F=(1000daN, 1500daN, 2000daN)

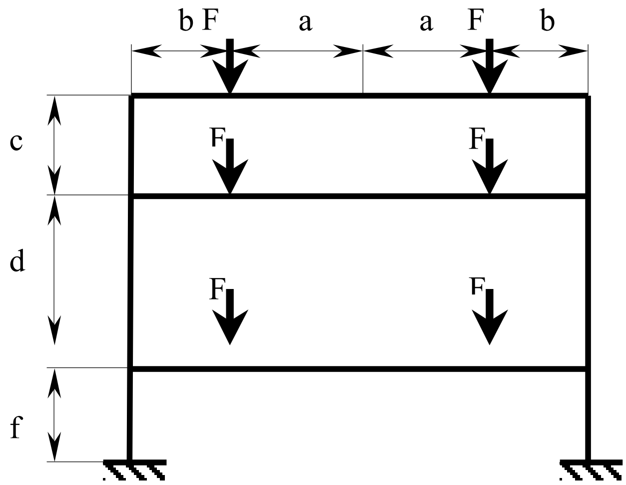



Fig. 10 Loading systems with 2 multi level forces

**Chapter 4, „ Calculation for the action mechanism resistance used on multi-level platforms"** treats and presents the tiller mechanism presented in the system form Fig 11, as following:

-the stress is determined for each moment and the chart is presented with the aid of Matchad Programme;

-the deviation of the beam is determined for the maximum stress points: the point from the half of the beam, and the moments when the Forces $F_1$ and $F_2$ are applied.

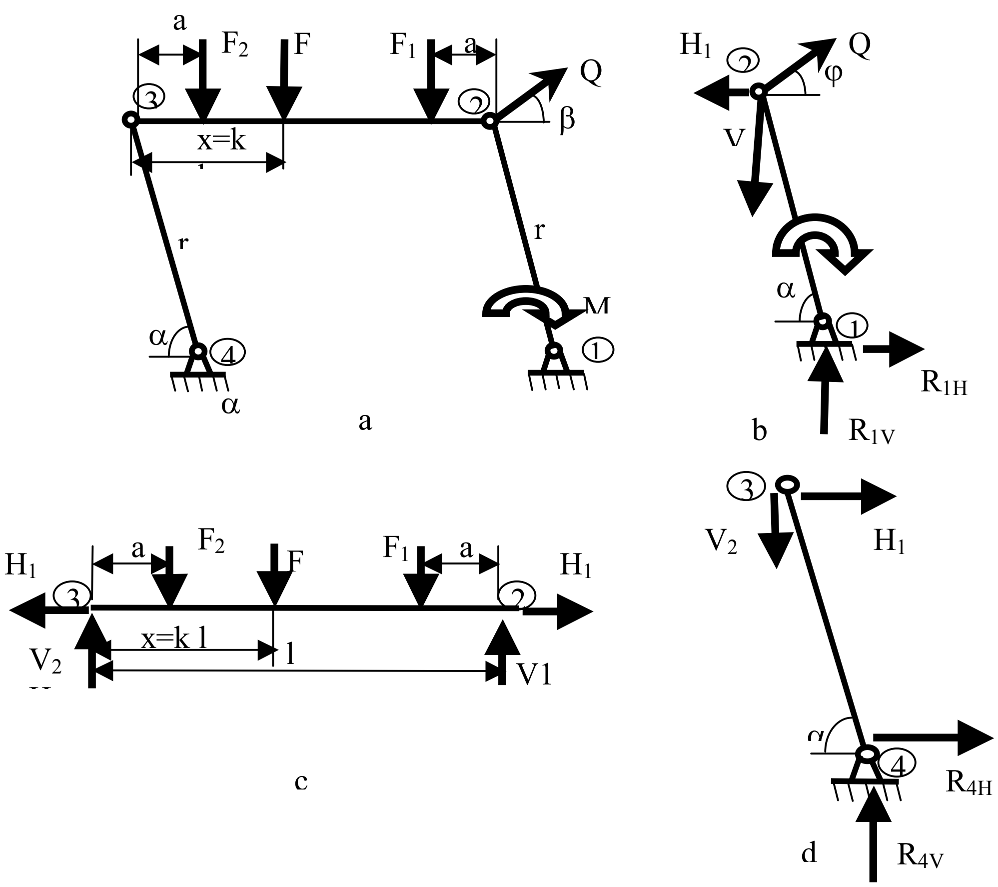



Fig. 11 Loading scheme

M – introducing moment of the crank ; α- bended crank; r- height of the crank;

Parameters adopted:

- Strength (1000daN,1500daN,2000daN) ;

-the time of the climb and the fall of the platform is 10 s(2s,6s,10s) ;

-the length of the platform l=430 cm

-a- distance of applying the force $F_1$ si $F_2$ a=λl, λ=0,25 ; r- the height of the platform r=(1,4-1,8);

-r-the height of the platform r=180 cm; α- the angle of the crank $\alpha(t)=\omega(t)\cdot t$

$\omega(t)=0{,}5\dfrac{3{,}14}{t_u}$ ;

-$t_u$- mechanism allotted time to reach the optimum position, $t_u$=10 s;

-ε-the angle of the strength Q, ε(α)=arctg$\dfrac{1-\sin(\alpha)}{\cos(\alpha)}$ ; A- cross-sectional area A=76,2cm$^2$;

-W-the modulus of the strength W=254,79cm$^3$; k-constant k=(0,4-0,6); k=0,4

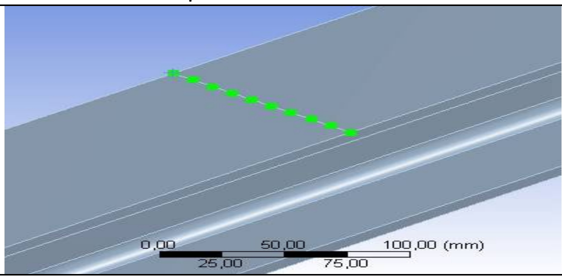
***In chapter 5 „ STRUCTURE ANALYSIS OF A PLATFORM USING THE FINITE ELEMENT METHOD”*** is presented the analysis of the parking systems shown in the chapter 3 using Ansys program and the results are analised and compared with analythical method. For a higher safety regarding the design of a steel structure, specialty literature implies the use of at least two methods:

-analythical methods (using the hypotheses and the calculation from folosind ipotezele şi calculele din *Material Resistance*);

-numerical methods (who use the finite element method).

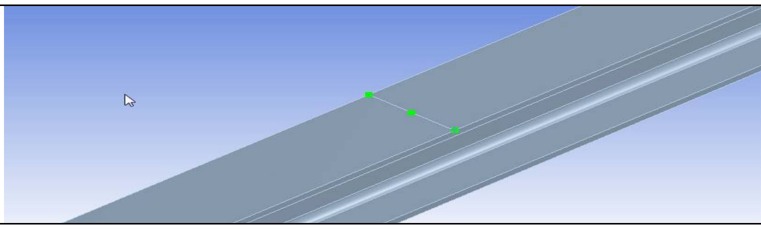
*Case study A- loading system with two forces (fig. 8)*

TABLE 1 The centralization of the results from point 4




| Punctul 4 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Deformation on Y (mm) | 0,86529 | 0,83221 | 0,80906 | 0,79022 | 0,7796 | 0,77948 | 0,78989 | 0,80957 | 0,83234 | 0,86516 |
| Equivalent stress | 637.89 | 94.578 | 99.293 | 126.09 | 148.39 | 180.58 | 146.15 | 71.124 | 85.142 | 637.57 |
| Punctul 3 | | | | | | | | | | |
| Deformation on Y(mm) | 0,8655 | 0,83227 | 0,80913 | 0,79029 | 0,7796 | 0,77953 | 0,78995 | 0,80963 | 0,8324 | 0,86531 |
| Equivalent stress | 643.3 | 95.099 | 100.08 | 126.96 | 149.18 | 181.44 | 147.03 | 71.788 | 85.616 | 642.86 |

TABLE 2 The centralization of the results a rezultatelor from the beam center



| Beam center | | | |
|---|---|---|---|
| Node No. | 1 | 2 | 3 |
| Equivalent stress MPa | 24.599 | 24.599 | 24.599 |

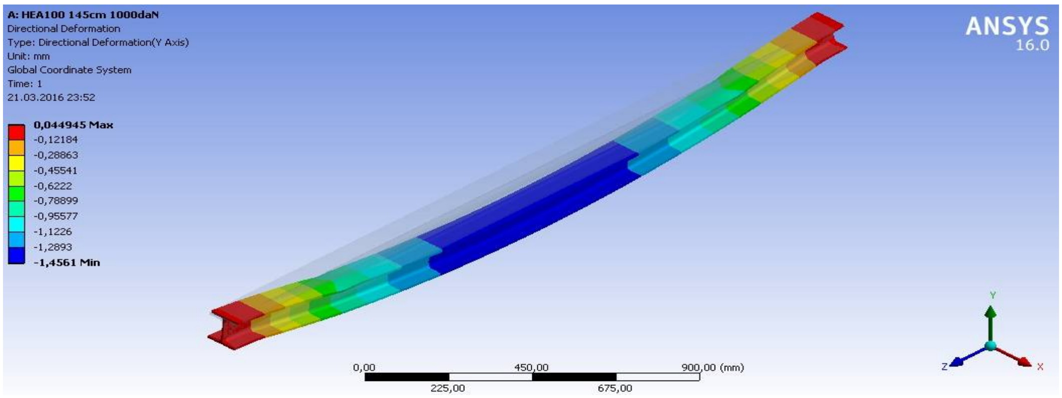



Fig. 12 Y deformation in 4 point

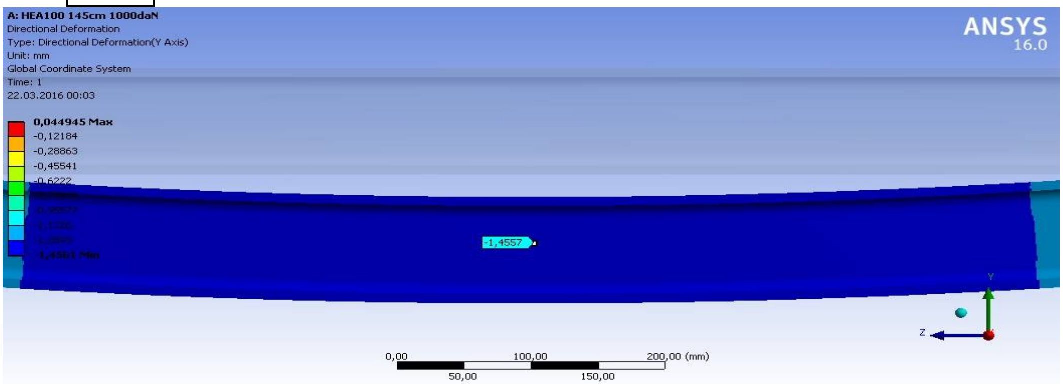



Fig.13 Center deformation

*Case study B- loading system with 4 forces*

TABLE 3 The centralization of the results in the point of application of forces

| Point 3 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Node No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Y Deformation | 0.196 | 0,1412 | 0,09468 | 0,054 | 0,028 | 0,028 | 0,054 | 0,094 | 0,141 | 0,196 |
| Equivalent stress | 161.06 | 26.754 | 19.358 | 28.961 | 60.70 | 60.70 | 28.96 | 19.35 | 26.74 | 161.0 |
| Point 4 | | | | | | | | | | |
| Node No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Y Deformation | 0,196 | 0,141 | 0,094 | 0,054 | 0,028 | 0,028 | 0,054 | 0,094 | 0,141 | 0.196 |
| Equivalent stress | 157.0 | 26.14 | 19.03 | 28.56 | 60.21 | 60.21 | 28.56 | 19.03 | 26.14 | 157.0 |

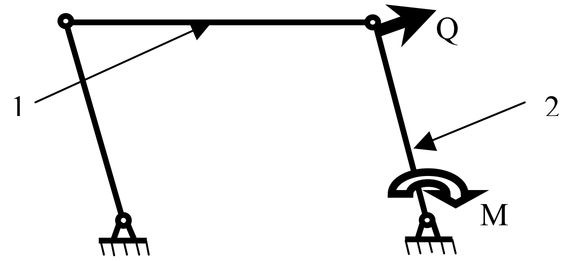
TABLE 4 The centralization of the results for the center of the intervals 3-4 and 6-7

| Points form the center of the interval 3-4 | | | |
|---|---|---|---|
| Y Deformation (mm) | 0.035296 | 0.05196 | 0.035296 |
| Equivalent stress | 23.599 | 23.599 | 23.599 |

| Points form the center of the interval 6-7 | | | |
|---|---|---|---|
| Y Deformation (mm) | 0.0305299 | 0.035198 | 0.035299 |
| Equivalent stress | 23.599 | 23.599 | 23.599 |

***Chapter 7 „THE EXPERIMENTAL ANALYSIS OF STRESSES IN THE ACTUATING MECHANISM OF A PLATFORM ATTACHED TO A CAR PARK”.*** In this chapter we use a template representing the stationed vehicle in a small parking (fig. 14) and through the method of electro-resistive tensometry is established the stress value from the beam for differents loads (F) and for differents positions of α angle.

The results obtained experimentaly are analysed and compared wuth the analythical results. (table 5, table 6).



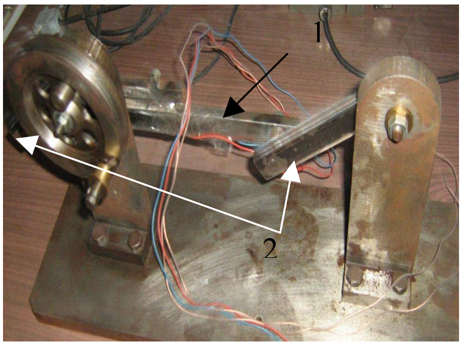




Fig.14. General view with the template that symbolises a lifting for a vehicle

*Observation: the errors between experimental and analythical stresses (noted with* $\Delta_1$ *și* $\Delta$*) have been determined with the formulas (1) și (2).*

$$\Delta_1 = \frac{|\sigma_{\exp} - \sigma_{56}|}{\sigma_{56}} \cdot 100 \qquad (1) \qquad \Delta = \frac{|\sigma_{\exp} - \sigma_{ech56}|}{\sigma_{ech56}} \cdot 100 \qquad (2)$$

Table 5. The centralization af the analythical results and the comparisons with the experimental ones

| F (N) | α ($^0$) | $F_1$ (N) | $F_2$ (N) | $V_1$ (N) | $V_2$ (N) | $H_1$ (N) | $\sigma_{56}$ (MPa) | $\sigma_{ech56}$ (MPa) | Δ (%) | $\Delta_1$ (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1224,6 | 90 | 378,185 | 846,415 | 548,107 | 676,493 | 0 | 8,266 | 8,266 | 2,986 | 2,986 |
| 254,59 | 65 | 78,623 | 175,967 | 113,95 | 140,64 | 65,582 | 1,718 | 2,046 | 5,145 | 11,703 |
| 402,79 | 50 | 124,931 | 278,399 | 180,281 | 222,509 | 186,707 | 2,719 | 3,652 | 5,761 | 29,848 |
| 461,61 | 20 | 142,556 | 319,054 | 206,608 | 255,002 | 700,613 | 3,116 | 6,619 | 8,516 | 48,916 |
| 254,54 | 90 | 78,608 | 175,932 | 113,927 | 140,613 | 0 | 1,718 | 1,718 | 0,271 | 0,271 |
| 254,59 | 65 | 78,623 | 175,967 | 113,95 | 140,64 | 65,582 | 1,718 | 2,046 | 5,145 | 11,703 |
| 254,57 | 50 | 78,617 | 175,953 | 113,941 | 140,629 | 118,002 | 1,718 | 2,308 | 1,923 | 26,991 |
| 254,93 | 20 | 78,728 | 176,202 | 114,102 | 140,828 | 386,922 | 1,721 | 3,655 | 10,13 | 48,156 |

In fig. 15 are presented the variations of the stress function of **α** angle

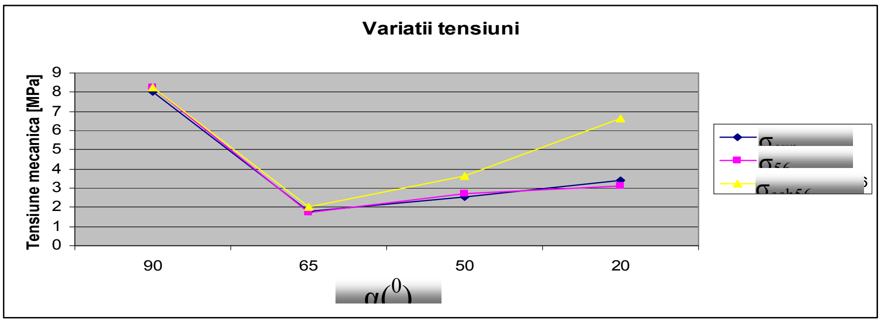



Fig. 15 Variations of the stress function of **α** angle

Table 6. The centralization af the analythical results and the comparisons with the experimental ones

| F (N) | α ($^0$C) | $F_1$ (N) | $F_2$ (N) | $V_1$ (N) | $V_2$ (N) | $\sigma_{56}$ (MPa) |
|---|---|---|---|---|---|---|
| 254 | Orice valoare | 78,441 | 175,559 | 113,685 | 140,315 | 1,714 |

***Chapter 8. „PERSPECTIVES AND CONCLUSIONS OBTAINED IN THE STUDY OF THE CAR PARKS ”.*** The car parks represents a special issue regarding the steadiness because these contains a few internal walls. The structural steadiness is removed by using a rigid frame and longitudinal arms at the outer edge of the building.

It is recomended :

- the distribution of the columns in the building plan to be as possible uniform;
- the rods are realized with full beams which can be made form rolled profiles;
- the rods are fixed by the columns is made by articulated or rigid links .
- the columns are fixed in the foundation by articulated links.
- in order to assure the steadiness of the structure in a cross direction the frontons will have bracings or diaphragms made from corrugated tin panels of the closure.
- suitable materials for the exterior walls are corrugated tables, with or without thermic isolation.

The experimental results have been validated with the analythical methods presented in the previous chapters that have been implemented in automatic calculation. Also, to make easier the following of the analythical design, have been reminded the most importants automatic calculation formulas, used to validate the experimentals results.

*In chapter 3 „ EFFORTS AND MECHANICAL STRESSES IN THE STRUCTURE OF THE CAR PARKS”* have been studied 3systems types and have been obtained the graphic representatins for stress variation function of the dimensional and F force.

As a result of the study we have the following conclusions:

- the solid structure is made for all of the 3 versions by using „I” wide profile structura solidă se realizează pentru cele 3 variante folosind profilul lat „I” with hard soles parallel execution series HEM, the value of the stress on these intervals is very low;
- the stress variation is influenced directly by the force variation, the car height variation is low, este influenţată direct proporţional de variaţia forţei, variaţia înălţimii autoturismui este mică, in some cases can neglect;
- the economic profile in terms of the material used is the „I” wide profile profilul economic din punct de vedere al materialului folosit este profilul lat „I” with smaller soles inclined width INP met in all of the 3 of the load versions;
- for case A (Loading system with two forces) the maximum stress is registered in the interval determined by the two F forces, case B (Loading system with four forces) the maximum stress is registered in the application points of F force, but for case C (Loading system with two storey forces) the maximum stress is registered arround the columns and this can have bigger values beside the stress values registered in the application of points of F force;
- for car parking systems the maximum stress is registered in the columns of the system ( case C), for the car parking systems with one level the maximum values are registered in the application points of the F force respectively the points of the connection between the car wheels and the platform;

*In chapter 4 „ THE CALCULATION OF THE RESISTANCE FOR THE ACTUATING MECHANISM OF THE STOREY PLATFORMS’’* is studied the mechanism of a car parking actuated by an electric motor. After analysing the informations obtained we can identify the most requested point of the mechanism and the amplitude of the stresses În urma analizei datelor obţinute putem identifica punctul cel mai solicitat al mecanismului, respectiv amplitudinea tensiunilor depending on the position of the mechanism at a set time as folows :

- the stress value decrease with increasing t time, the stress is at the maximum value in the firts seconds of moving the platform;

-the maximum value of the stress is registered in the application point of the F force, the minimum value of this structure is registered at the ends of the beam;

- the stesses are grouped in three range of values according to t time and F force;

- force Q has a constant distribution for the whole interval of the platform for t=10s force Q has nulle value;

- the beam deformation by y axis is not influenced by the variation of the **α** angle and by the variation of the lifting and the lowering of the platform, the deformation is time deformația grinzii după axa y nu este influențată de variația ungiului **α** și de variația timpului de urcare și coborâre a platformei, deformația este proportionaly with the variation of the F force ( the weight of the vehicle).

*The finite element method vas been related in chapter 5 „ THE ANALYSIS OF THE STRUCTURE OF A STOREY PLATFORM WITH THE FINITE ELEMENT METHOD"* where we studied the structure of the car parking systems analythicaly presented in chapter 3.

In the tables 7 and 8 are presented the experimental results and the compares with the analythical ones for case A ( Loading system with two forces) and case B ( Loading system with four forces ).

TABLE 7 The centralization of the analythical results and compares with the experimental ones (Case A)

| a (mm) | b (mm) | h (mm) | F (N) | profile | $\sigma_{exp}$ | $\sigma_{an}$ | $\varepsilon_{an}$ (mm) | $\varepsilon_{exp}$ (mm) | $\Delta$ (%) | $\Delta_1$ (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1520 | 400 | 1450 | 10000 | HEA100 | 24,599 | 27,5 | 1,27 | 1,456 | 14,6 | 10,4 |
| 1520 | 400 | 1450 | 10000 | HEB100 | 18,795 | 20,90 | 0,98 | 1,112 | 13,4 | 10 |
| 1520 | 400 | 1450 | 10000 | HEM100 | 8,1395 | 9,065 | 0,45 | 0,397 | 10.9 | 10,2 |
| 1520 | 400 | 1450 | 10000 | INP100 | 63,2 | 57,5 | 1,78 | 1,970 | 10,6 | 9,9 |

TABLE 8 The centralization of the analythical results and compares with the experimental ones (Case B)

| a (mm) | b (mm) | h (mm) | F (N) | profile | $\varepsilon_{an}$ (mm) | $\varepsilon_{exp}$ (mm) | $\Delta$ (%) |
|---|---|---|---|---|---|---|---|
| 1520 | 400 | 1450 | 10000 | HEA280 | 0,18 | 0,2046 | 13.6 |
| 1520 | 400 | 1450 | 10000 | HEB260 | 0,092 | 0,1037 | 12,7 |
| 1520 | 400 | 1450 | 10000 | HEM220 | 0,0719 | 0,0823 | 14,4 |
| 1520 | 400 | 1450 | 10000 | INP360 | 0,065 | 0,0710 | 9,2 |

The main conclusions from the study of the system trough the 2 experimental methods:

- forces $F_1$, $F_2$, reactions $V_1$ și $V_2$ and the stress $\sigma_{56}$ are not depending by **α** angle **;**
- for **α**=90° the value of the reaction $\mathbf{H_1}$ is nulle, reaction $\mathbf{H_1}$ increase considerably allong with the decreasing of the **α** angle**;**
- the error **Δ** (7.6) increase allong with the decrease of the **α** angle**;**
-the variation of the mouvement ($\boldsymbol{\varepsilon_y}$) registered trough the two angles is lower, approximately 8%;
- the errors obtained with electro-resistive tensometry method erorile obținute cu metoda tensometriei electro-rezistive frames in the permissible limit, in case of optic tensometry have been obtained very big errors.
- the force reader is working in a big measuring range ( in this study are used small forces, maximum 2 kN), and due to this fact we can have errors in measuring the F force applied to the mechanism;
- after many experimental tests the joints of the mechanism may suffer plastic deformations;

The main contributions of the author, in the literature concerning the calculation of the resistance mechanisms of bunk actuation, by studying the tensions in this work are the following :

-establishing an experimental model with its own wide practical design mechanisms attached to a bunk room;

-founding a solution by simulating a vehicle parked on the platform;

- experimental assemblage and the equipment used during the study (force transmission device with the method of putting in contact the feed screw actuators, force transducers, form-driven vehicle, platform, data acquisition system, etc.);

-the way of application of the two experimental methods;

-thinking of a programme for the analysis of experimental data, considering the requests in the field of elastic where Hooke's law can be applied, of the signal deviation specific to a signal that can be obtained from mechanical tension, where the unit of measurement is MPa;

-implementation of the results of the graphs plotting aid programs (such as Microsoft Excel Files), which has led to a easier interpretation of experimental results.

Through the study undertaken in this thesis, the author considers that he contributed to the development of the research in the area of municipal Multi-storey as a starting point for further research undertaken by specialists/designers working in this area.

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