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# The curving calculation of a mechanical device attached to a multi-storey car park

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**Abstract**. Study bunk storage systems for motor vehicles developed much lately due to high demand for parking in congested city centers. In this paper we propose to study mechanism drive bunk platforms for dynamic request. This paper aims to improve the response mechanism on a platform behavior self during operation of the system and identify hot spots. In this paper we propose to analyze the deformations of the superposed platform in the points of application of the exterior forces produced by the weight of the vehicle in a dynamic way. This paper aims to automate the necessary computation for the analysis of the deformations of the superposed platform using Netlogo language.

## 1. Introduction

In previous studies [1], [2] were presented mechanical and kinematic schemes of different types of existing storey car parks:

- bunk parking system with mobile boxes, in this case the platform is supported by a cable wound on a drum;
- car parks system, in this case the platform is supported by a cable or chain driven by an electric motor;
- bunk parking system with fixed boxes, car platform is a movement in the vertical and horizontal movement, it slides in the fixed structure of the drive shaft of the electric motor via a cable;
- second places parking system, in this case the car platform is driven by a hydraulic cylinder.

These systems have a number of disadvantages to each type of structure established in part, however they are the best solution to achieve in crowded parking lots in the center of large cities where the ground surface does not allow the construction of a parking ground. It is necessary to periodically check the cable (chain), roller bearings (gear) and electric motor combined welds. There are two types of car parking systems: traditional and automated long-term automatic car parking systems are more efficient compared to traditional garages. Multi-storey car systems are less expensive automated parking place because they require a large amount of construction and a small area on the ground [1], [2] .

This paper aims to automate the necessary computation for the analysis of the deformations of the superposed platform using NetLogo language [3].

## 2. Patterns of kinematic scheme for a parking structure bunk

In Figures 1 and 2 are shown kinematic diagrams of two-storey parking systems with two storage locations of vehicles, upper end platform is driven by a hydraulic cylinder (Figure 1) and an electric motor (Figure 2). In both variants of unlocking the vehicle parked on the upper platform to be released lower platform which is a major disadvantage. The space required for placing the system of Figure 2 must be greater than the length of a car as car parking upper deck flips it to the lower deck. Both systems have low height, increasing the number of parking spaces for these systems can be multiplied in number to the basement blocks, shops, etc.

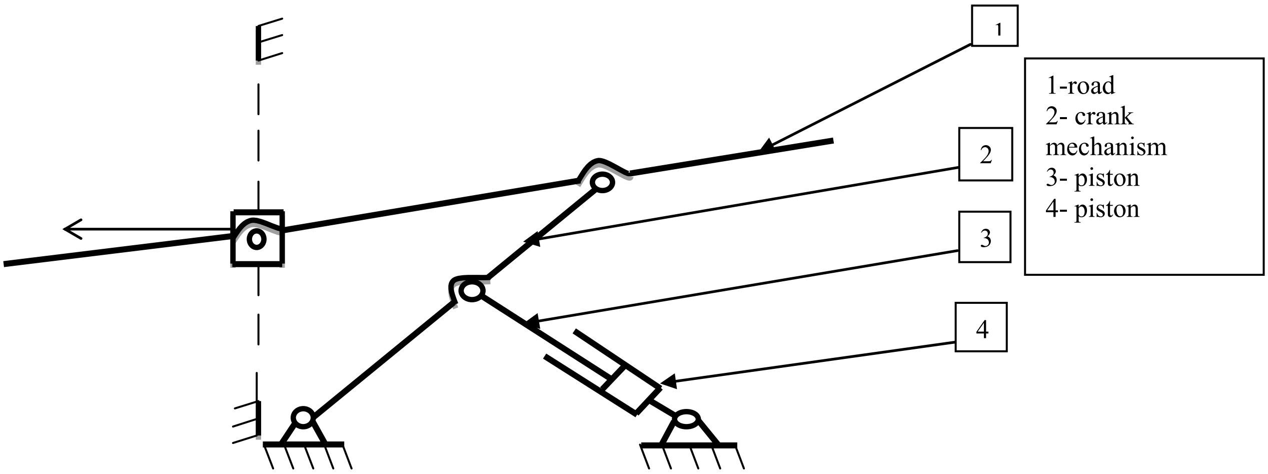


**Figure 1.** Hydraulic mechanism kinematic scheme

The system of Figure 1 is the simplest parking system and its installation does not require training the surrounding area, parking space height can be adjusted according to the height of the car parked. Both systems require not authorized personnel for handling; they can be operated even by the head auto. Platform system of Figure 2 can be driven by a cable wound on a drum driven by an electric motor. In the event of a power failure the system can be equipped with a mechanism for manual operation or with an electric generator.

Both systems require a maintenance contract to ensure safe operation. There are a number of areas where hydraulic systems offer many advantages that cannot be covered by electrical transmissions because hydraulics are usually characterized by a force much greater torque and power. Platforms powered or hydraulic structures are designed for a particular application payload is clearly defined, where the payload increases appreciably approximately 20% electrical system does not operate normally due to overload.

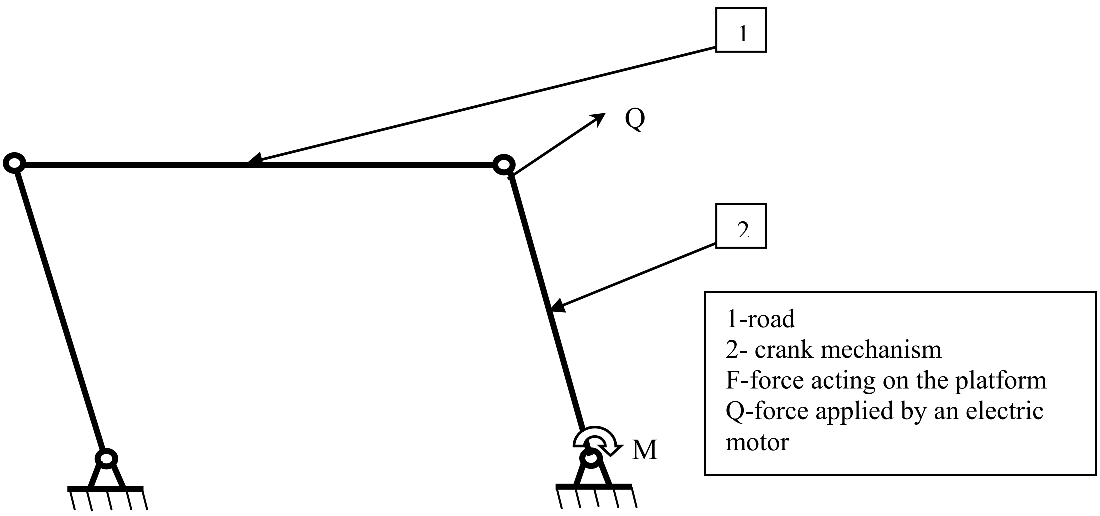


**Figure 2.** Scheme kinematic mechanism driven by an electric motor

On the other hand, a hydraulic system can accommodate a much wider range of operating parameters, usually a properly designed hydraulic system can be overloaded by up to 50% more efficient operation and features [4-7].

## 3. Curving calculation in point C

The curving application of force F can be determined with the aid of Mohr-MAXWELL [8-11]. To determine $F_1$ and $F_2$ forces the following conditions have to concure:

$F_1+F_2=F$ and $F_2(kl-a)=F_1[(1-k)l-a]$ (1)

After solving the system 1, $F_1$ and $F_2$ forces can be determined (relation 2)

$$F_1(k,a,l,F)= F\frac{k\cdot l-a}{l-2\cdot a}; \qquad F_2(k,a,l,F)= F\frac{(1-k)\cdot l-a}{l-2\cdot a} \tag{2}$$

The verifying rule for point k=0,5 $F_1=F_2$

Unknown values of the system: $Q=Q(t,k,a,l,r,F)$; $V_1=V_1(t,k,a,l,F)$; $V_2=V_2(t,k,a,l,F)$; $H_1=H_1(t,k,a,l,F)$; $R_{1V}=R_{1V}(t,k,a,l,r,F)$; $R_{1H}=R_{1H}(t,k,a,l,r,F)$; $R_{4V}=R_{4V}(t,k,a,l,r,F)$ $R_{4H}=R_{4H}(t,k,a,l,r,F)$

In order to calculate reactions an equilibrium equation must be written. Is the equation of moment 1 and the equation of coordinate axes proiections (Figure 3). After solving the equations system the following unknown values can be obtained:

$$Q(t,k,a,l,r,F)=\frac{\cos\alpha\cdot[F\cdot l-a\cdot(F_1-F_2)-F_2\cdot l+r\cdot\sin\alpha\cdot F_1\cdot a+r\cdot\sin\alpha F_2\cdot l-r\cdot\sin\alpha F_{2.}\cdot a]}{\sin\alpha\cdot(\sin\alpha\cdot\cos\varepsilon+\sin\varepsilon\cdot\cos\alpha)};$$

$$V_1(t,k,a,l,F)=\frac{F\cdot l-F_1\cdot a-F_2\cdot l+F_2\cdot a}{l}; \quad V_2(t,k,a,l,F)=\frac{F_1\cdot a+F_2\cdot l-F_2\cdot a}{l}; \tag{3}$$

$$H_1(t,k,a,l,F)=\frac{\cos\alpha\cdot(F_1\cdot a+F_2\cdot l-F_2\cdot a)}{\sin\alpha\cdot l};$$

$$R_{1V}(t,k,a,l,r,F)=\frac{F\cdot l-F_1\cdot a-F_2\cdot l+F_2\cdot a}{l}-Q\sin\varepsilon;$$

$$R_{4V}(t,k,a,l,r,F)=-\frac{F_1\cdot a+F_2\cdot l-F_2\cdot a}{l};$$

$$R_{1H}(t,k,a,l,r,F)=\frac{\cos\alpha\cdot(F_1\cdot a+F_2\cdot l-F_2\cdot a)}{\sin\alpha\cdot l}-Q\cos\varepsilon;$$

$$R_{4H}(t,k,a,l,r,F)=-\frac{\cos\alpha\cdot(F_1\cdot a+F_2\cdot l-F_2\cdot a)}{\sin\alpha\cdot l}$$

We have a moment equation of real charging values as seen in Figure 3 on each of the all 5 steps:

-moment 1-2 equation:

$M_{12}(t,k,a,l,r,F,x)= -x\cdot(H_1(t,k,a,l,F)\cdot\sin\alpha+ V_1(t,k,a,l,F)\cdot\cos\alpha)+Q(t,k,a,l,F)\cdot x\cdot(\sin\varepsilon\cdot\cos\alpha+\cos\varepsilon\cdot\sin\alpha)$ (4)

-moment 3-4 equation:

$M_{34}(t,k,a,l,F,x)=x\cdot( H_1(t,k,a,l,F)\cdot\sin\alpha- V_2(t,k,a,l,F)\cdot\cos\alpha)$ (5)

-moment 6-3 equation:

$M_{25}(t,k,a,l,F,x)= V_1(t,k,a,l,F)\cdot x$

$M_{56}(t,k,a,l,F,x)= V_1(t,k,a,l,F)\cdot x-F_1(k,a,l,F)(x-a)$ (6)

$M_{63}(t,k,a,l,F,x)= V_1(t,k,a,l,F)\cdot x-F_1(k,a,l,F)\cdot(x-a)-F_2(k,a,l,F)(x-l+a)$

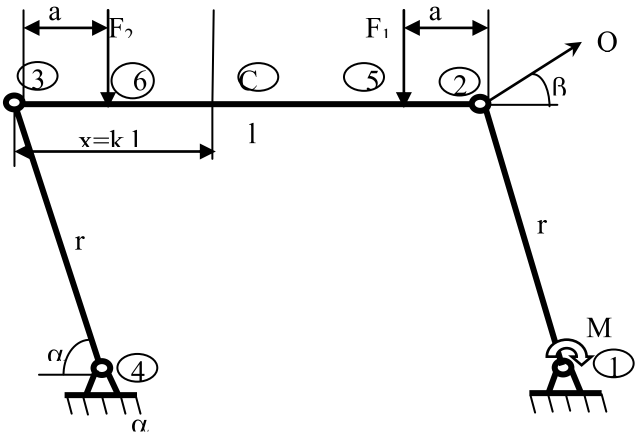


**Figure 3.** Charging figure

The single force F produces a moment equation presented in Figure 4.

This equation are: [3-5]

$m_{25}(t,k,a,l,x)= V_{C1}(t,k,a,l)\cdot x$ (7)
$m_{5C}(t,k,a,l,x)= V_{C1}(t,k,a,l)\cdot x$
$m_{C6}(t,k,a,l,x)= V_{C1}(t,k,a,l)\cdot x-1(x-l+kl)$
$m_{63}(t,k,a,l,x)= V_{C1}(t,k,a,l)\cdot x-1(x-l+kl)$

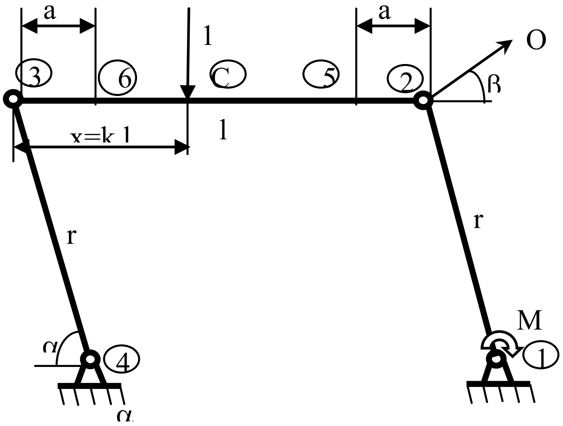


**Figure 4.** Single force charging

After solving the system equation the following unknown values can be found:

$V_{C1}=k; \quad V_{C2}=1-k$ (8)

Over the point F where the force is pressing, a curving point do occures. This curving can be calculated using the MOHR-MAXWELL method, using relations (4-7). Considering the type profile the deformation point is shown (relation 9)

$$\mathbf{fc}=\frac{1}{E\cdot I}\Big(\int_0^a M_{25}(t,k,a,l,r,F,x)\cdot m_{25}(t,k,a,l,r,x)dx+\int_a^{l-a} M_{56}(t,k,a,l,r,F,x)\cdot m_{5C}(t,k,a,l,r,x)dx$$

$$+\int_a^{l-a} M_{56}(t,k,a,l,r,F,x)\cdot m_{C6}(t,k,a,l,r,x)dx+\int_{l-a}^{l} M_{63}(t,k,a,l,r,F,x)\cdot m_{63}(t,k,a,l,r,x)dx\Big) \quad (9)$$

Relation 9 can be introduced in an application. An automatic calculation programme can calculate the analitical equation of the curving point where the force F is pressing on relation (10).

$$\text{fc(t,k,a,l,r,F,E,I,x)}=\frac{1}{E\cdot I}\cdot\left[\frac{l}{3}\cdot F\cdot k^2\cdot a^3-\frac{l}{6}\cdot F\cdot a\cdot k\cdot f_{c1}(t,k,a,l,r,F,E,I,x)\right]+$$
$$+\frac{1}{E\cdot I}\cdot\left[\frac{(-l)}{6}\cdot a^3\cdot F\cdot\frac{4\cdot k\cdot a+a-3\cdot k\cdot l}{(-l+2\cdot a)}\cdot k-\frac{l}{6}\cdot a\cdot F\cdot f_{c2}(t,k,a,l,r,F,E,I,x)\right]+$$
$$\frac{1}{E\cdot I}\cdot\left[\frac{(-l)}{6}\cdot a^2\cdot F\cdot f_{c3}(t,k,a,l,r,F,E,I,x)+\frac{(-l)}{6}\cdot l^2\cdot F\cdot f_{c4}(t,k,a,l,r,F,E,I,x)\right]+$$
$$+\frac{1}{E\cdot I}\cdot\left[\frac{l}{6}\cdot F\cdot f_{c5}(t,k,a,l,r,F,E,I,x)\right] \tag{10}$$

Due to the big size of the curving equation the following notations are being calculated in relations (11-15)

$\text{fc}_1\text{(t,k,a,l,r,F,E,I,x)}=$

$$\frac{(-k\ )\cdot l^3+6\cdot k\ \ \cdot l^2\cdot a+2\cdot l^3-9\cdot l^2\cdot a-9\cdot l\cdot a^2\cdot k+12\cdot l\cdot a^2+4\cdot a^3\cdot k-5\cdot a^3}{(-l+2\cdot a)} \tag{11}$$

$$\text{fc}_2\text{(t,k,a,l,r,F,E,I,x)}=\frac{(-k^2)\cdot l^3-3\cdot k^2\cdot l\cdot a^2+3\cdot l^2\cdot k\cdot a+6\cdot l\cdot a^2\cdot k+4\cdot k^2\cdot a^3}{(-1+2\cdot a)}+$$
$$+\frac{(-9)\cdot a^3\cdot k+l^3-3\cdot l^2\cdot a-3\cdot l\cdot a^2+5\cdot a^3}{(-1+2\cdot a)} \tag{12}$$

$$\text{fc}_3\text{(t,k,a,l,r,F,E,I,x)}=\frac{4\cdot k^2\cdot a^2-3\cdot k\cdot a^2-9\cdot a\cdot k^2\cdot l+6\cdot a\cdot k\cdot l+6\cdot k^2\cdot l^2-a^2}{(2\cdot a-l)}+$$
$$+\frac{3\cdot l\cdot a-6\cdot k\cdot l^2}{(2\cdot a-l)} \tag{13}$$

$$\text{fc}_4\text{(t,k,a,l,r,F,E,I,x)}=\frac{l^2\cdot k^2\cdot a+k^2\cdot l\cdot a^2-10\cdot l\cdot a^2\cdot k+4\cdot l^2\cdot k\cdot a-l^3\cdot k}{[(2\cdot a-l)\cdot(a-2\cdot l)]}+$$
$$+\frac{3\cdot a^3\cdot k-12\cdot a\cdot k\cdot l+12\cdot k\cdot a^2+3\cdot a\cdot k^2\cdot l-6\cdot k^2\cdot a^2+3\cdot k\cdot l^2+9\cdot l\cdot a^2-5\cdot l^2\cdot a}{[(2\cdot a-l)\cdot(a-2\cdot l)]}+$$
$$+\frac{l^3-3\cdot a^3+9\cdot l\cdot a-6\cdot a^2-3\cdot l^2}{[(2\cdot a-l)\cdot(a-2\cdot l)]} \tag{14}$$

$$\text{fc}_5\text{(t,k,a,l,r,F,E,I,x)}=\frac{(-12)\cdot a\cdot k\cdot l^3-3\cdot l^4+6\cdot a^4-12\cdot k\cdot a^4-3\cdot a^2\cdot l^2-9\cdot a^3\cdot l}{[(2\cdot a-l)\cdot(a-2\cdot l)]}+$$
$$+\frac{9\cdot l^3\cdot a+l^5+9\cdot a^2\cdot k\cdot l^2+12\cdot a^3\cdot k\cdot l+k^2\cdot l^4\cdot a+3\cdot k^2\cdot l^3\cdot a+44\cdot k\cdot l\cdot a^4}{[(2\cdot a-l)\cdot(a-2\cdot l)]}+$$
$$\frac{(-3)\cdot k^2\cdot l\cdot a^3-6\cdot k^2\cdot l^2\cdot a^2-19\cdot k^2\cdot l\cdot a^4-7\cdot k\cdot l^3\cdot a^2-23\cdot k\cdot l^2\cdot a^3+4\cdot k\cdot l^4\cdot a}{[(2\cdot a-l)\cdot(a-2\cdot l)]}+$$
$$\frac{k^2\cdot l^3\cdot a^2+9\cdot k^2\cdot l^2\cdot a^3+3\cdot l^4\cdot k-k\cdot l^5-17\cdot k\cdot a^5+6\cdot k^2\cdot a^4+8\cdot k^2\cdot a^5}{[(2\cdot a-l)\cdot(a-2\cdot l)]}+$$

$$+\frac{(-25)\cdot l\cdot a^4+6\cdot a^2\cdot l^3+14\cdot a^3\cdot l^2-5\cdot l^4\cdot a+9\cdot a^5}{[(2\cdot a-l)\cdot(a-2\cdot l)]} \qquad (15)$$

Relation 10 is introduced into a programme of automatic calculation. This programme is using all the parameters shown below. At the end of the calculation the curving calcules of point F are being obtained.

$$F\left(\frac{f_c}{E\cdot I}\right)\text{(Table 1).}$$

Entrance parameters:
-force F (1000daN,1500daN,2000daN) ;
-climbing time and descending time of the platform is 10 s (2s,6s,10s) ;
-platform length l=430 cm.
-a- pressing distance of forces $F_1$ and $F_2$ a=λl, λ=0,25 ;
-r- platform height r=180 cm;
-α crank angle $\alpha(t)=\omega(t)\cdot t \quad \omega(t)=0{,}5\frac{3{,}14}{t_u}$ ;
-$t_u$- necessary time for the crank to reach the optimal position $t_u$=10 s;
-ε-force angle Q, ε(α)=arctg $\frac{1-\sin(\alpha)}{\cos(\alpha)}$ ;
-A area of the section A=76,2cm$^2$;
-W-module endurance W=254,79cm$^3$;
-k-constant k=(0,4-0,6); k=0,4
-r platform height r=(1,4-1,8);

**Table 1.** Point C curving

| Ascending/ descending time of the platform | F=1000daN | F=1500daN | F=2000daN |
|---|---|---|---|
| t-2s | 2168604602,678571 | 3252906904,017857 | 4337209205,357142 |
| t-6s | 2168604602,678571 | 3252906904,017857 | 4337209205,357142 |
| t-10s | 2168604602,678571 | 3252906904,017857 | 4337209205,357142 |

The curving reached in point 5 was calculated almost the same way. The results are presented in Table 2.

**Table 2.** Point 5 curving

| Ascending/ descending time of the platform | F=1000daN | F=1500daN | F=2000daN |
|---|---|---|---|
| t-2s | 3157821602.306547 | 4736732403.459821 | 6315643204.613095 |
| t-6s | 3157821602.306547 | 4736732403.459821 | 6315643204.613095 |
| t-10s | 3157821602.306547 | 4736732403.459821 | 6315643204.613095 |

## 4. Conclusions

A first conclusion that can be deducted from the curving of platform structure is that the value of deformation on point C is not influenced by the time of acending and descending of the platform (t).

The curve that accurs in point C is directly proportional to the growth of the force F and it doubles the multiplication of force F. This deformation produced in point C is very small comparing to the variation of time t and force F.

This study has the purpose to show the platform curving in point C and to present also its deformation in point 5. As it can be observed the maximum value was obtained in point 5 for F= 2000daN.

Similar to point C deformation on point 5 is not affected by the position of the platform.

Using dedicated software (NetLogo language) it allowed to automate the necessary computation for the analysis of the deformations of the superposed platform.

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