

DETERMINATION OF SUITABLE OPENING ANGLE OF HYDRAULIC SUPPORT LEGS FOR DESIGNING M46-130mm SELF-PROPELLED ARTILLERY

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Abstract: This paper determines a suitable opening angle of the hydraulic support legs of M46-130 mm self-propelled artillery. It is a combination of M46-130 mm field gun, mounted on KrAZ-255B 6x6 military truck chassis. Based on results of investigating the changes of forces and moments acting on artillery system in static condition when changing the opening angle of hydraulic support legs at critical fire angles, a suitable angle is selected at $\psi = 40^\circ$ and $\gamma = 20^\circ$. From that angle, this paper shows a table consists of geometric parameters, forces and moments acting on system. The results of this research are the input parameters to calculate, design and optimize structures of self-propelled artillery.

Keywords: M46-130 mm self-propelled artillery; Hydraulic support legs; Opening angle of hydraulic support legs; Static condition

1. INTRODUCTION

For medium and heavy artillery with long barrel like M46-130mm, 152mm-52 when mounted on a motorized wheeled or tracked chassis then the general structure of self-propelled artillery such as Caesar, Archer, Atmos 2000 artillery utilizes two hydraulic support legs at the rear back as shown in figure 1.



Figure 1. Archer (a) and Atmos 2000 (b) self-propelled howitzer [1].

During the process of firing, the middle and rear axles are clear of the ground by two hydraulic support legs to release the suspension system of the vehicle. Therefore, hydraulic support legs receive almost the whole firing impulse force and the weight of artillery system. The opening angle of the hydraulic support legs directly effects on static balance of artillery system, stroke length of piston-cylinder, length of hydraulic support legs, and forces and moments in hydraulic support legs.

Previous research is mainly concentrated on general information of theory and design of gun and ammunition [2-8]. [9] investigates the kinetic of guns which integrates on military trucks. In addition, [10] shows the basic theory of military engineering vehicle. However, the analysis related to opening angle of the hydraulic support legs of self-propelled artillery has not been investigated.

It is needed to find out of the opening angle of hydraulic support legs in order to determine the input parameters in design stage of M46-130mm self-propelled artillery. This paper presents steps to examine the changes of forces and moments

depending on the opening angle of hydraulic support legs to determine suitable values to meet given requirements when applying maximum recoil resistance force on system in the static equilibrium condition. In section 2 a model of M46-130mm self-propelled artillery is presented to establish static equilibrium equations. Based on some initial conditions, investigating the changes of forces and moments depends on the opening angle of hydraulic support legs and discussing the results in section 3. Finally, this paper is concluded in section 4.

2. MECHANICAL MODEL OF THE SYSTEM

In design stage, it is necessary to determine a suitable value of opening angle of hydraulic support legs to meet the following requirements:

- The artillery system must to satisfy static stable conditions in firing period.
- The compatibility between axial forces and bending moments in hydraulic support legs so that the maximum stress does not exceed the allowable value.
- The dimensions and weight of artillery system are within allowable limits.

2.1. Assumptions

- Rotary moment of projectile when moving in bore is ignored.
- Flexural rigidity of chassis, artillery structures, hydraulic support legs and ground are infinite. In addition, there is no gap between joints and assemblies.
- Artillery system is placed on a horizontal plane.

2.2. Mechanical model

Mechanical model of M46-130mm self-propelled artillery is shown in figure 2.

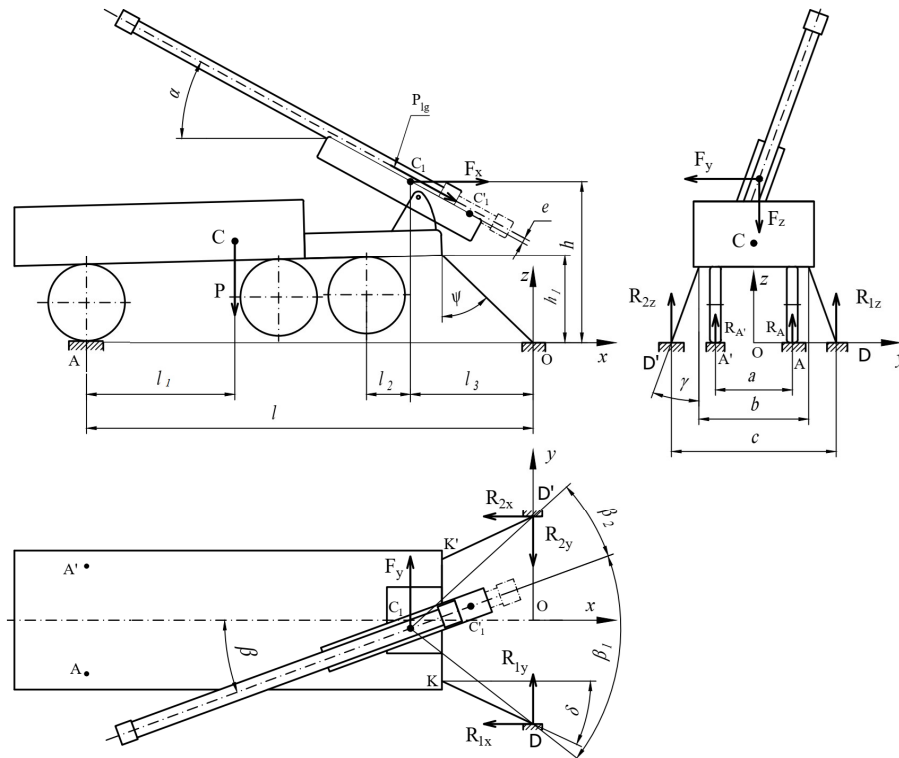


Figure 2. Model of M46-130mm self-propelled artillery.

Geometric characteristics and forces, moments acting on artillery system in the static condition are listed in table 1 and table 2.

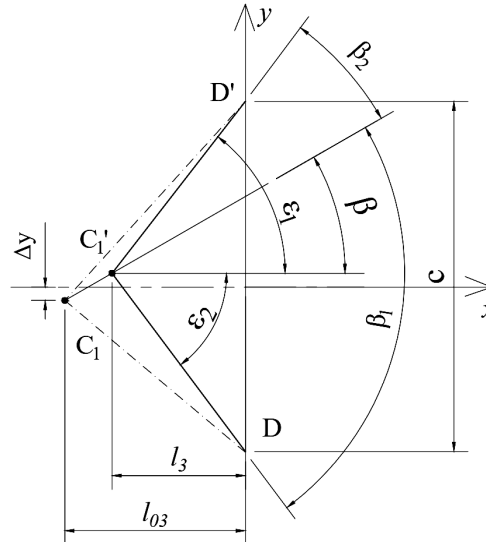
Table 1. Geometric characteristics of M46-130mm self-propelled artillery.

Notations	Descriptions
C	Center of gravity of artillery system
C_1, C_1'	Center of gravity of the recoiling parts before firing and at any instant
A, A'	Center of contact of left and right front wheels and ground
D, D'	Center of contact area between first and second spades hydraulic support leg (left and right hydraulic support leg) and ground
α	Angle of elevation (angle between the line through the axis of the bore and XOY plane)
β	Angle of traverse (angle between the line through the axis of the bore and XOZ plane)
γ	Angle between the projection of the hydraulic support legs on the YOZ plane and OZ axis
ψ	Angle between the projection of the hydraulic support legs on the XOZ plane and OX axis
δ	Angle between the projection of the hydraulic support legs on the XOY plane and OX axis
β_1, β_2	Angle between the projection of lines connect center of gravity of recoiling parts to spades on the XOY plane and the axis of the bore
e	Distance from the center of gravity of the recoiling parts to the axis of the bore
X	Displacement from beginning of counter recoil of recoiling parts with respect to guides (C_1C_1')
l	Distance from the midpoint of the center of two spades to front axle
l_1	Horizontal distance from AA' to C
l_2	Horizontal distance from C to the center of gravity of recoiling parts
l_{03} $l_3 = l_{03} - X \cos \alpha \cos \beta$	Distance from the midpoint of the center of two spades to the center of gravity of recoiling parts before firing and at any instant
h_{01} $h = h_{01} - X \sin \alpha \cos \beta$	Vertical distance from ground to the center of gravity of recoiling parts before firing and at any instant
h_1	Vertical distance from ground to KK'
a, b and c	Horizontal distance from A to A', K to K' and D to D'
Δy	Distance between the projection of the center of gravity of recoiling parts on the XOY plane and OX axis before firing

Table 2. Forces acting on artillery system.

Notations	Descriptions
$\vec{F} = (F_x, F_y, F_z)$	Recoil resistance force
$\vec{R}_A, \vec{R}_{A'}$	Normal reactions of ground on left and right front wheel at A and A'
$\vec{P}$	Weight of artillery system
m_r	Mass of the recoiling parts
$\vec{R}_1 = (R_{1x}; R_{1y}; R_{1z})$	Component reactions on spade of hydraulic support leg 1 (D)
$\vec{R}_2 = (R_{2x}; R_{2y}; R_{2z})$	Component reactions on spade of hydraulic support leg 2 (D')
$\vec{P}_{lg}$	Total pressure on breech

The relation between β_2, β_1 and other geometric parameters


 Figure 3. Figure used to determine β_2, β_1 .

From figure 3, we have the geometric relation to determine β_2, β_1 .

$$\begin{cases} \beta_1 = \varepsilon_2 + \beta \\ \beta_2 = \varepsilon_1 - \beta \end{cases} \quad (1)$$

with $\varepsilon_1, \varepsilon_2$ is calculated by

$$\begin{cases} \varepsilon_1 = \arctan\left(\frac{\frac{c}{2} + \Delta y - X \cos \alpha \sin \beta}{l_3}\right) \\ \varepsilon_2 = \arctan\left(\frac{\frac{c}{2} - \Delta y + X \cos \alpha \sin \beta}{l_3}\right) \end{cases} \quad (2)$$

There are the following relations among geometrical parameters ψ , δ , γ , θ and ε

$$\begin{cases}
 \sum X = F_x - R_{1x} - R_{2x} = 0 \\
 \sum Y = R_{1y} - R_{2y} + F_y = 0 \\
 \sum Z = R_A + R_{A'} + R_{1z} + R_{2z} - P - F_z = 0 \\
 \sum M_{DD'} = [P(l - l_1) - m_r g X \cos \alpha \cos \beta] + F_z l_3 - F_x h - (R_A + R_{A'})l - P_{lg} e \cos \beta = 0 \\
 \sum M_D (YOZ) = F_y h + (P \frac{c}{2} + m_r g X \cos \alpha \sin \beta) + P_{lg} e \sin \beta - R_{A'} (\frac{c}{2} + \frac{a}{2}) \\
 - R_A (\frac{c}{2} - \frac{a}{2}) - R_{2z} c + F_z (\frac{c}{2} + X \cos \alpha \sin \beta - \Delta y) = 0 \\
 \sum M_{C_1} (XOY) = (R_{2y} - R_{1y}) l_3 + R_{1x} (\frac{c}{2} - \Delta y + X \cos \alpha \sin \beta) \\
 - R_{2x} (\frac{c}{2} + \Delta y - X \cos \alpha \sin \beta) + P_{lg} e \sin \beta = 0
 \end{cases} \quad (6)$$

where $F_x = F \cos \alpha \cos \beta$, $F_y = F \cos \alpha \sin \beta$, $F_z = F \sin \alpha$ are the components of the recoil resistance force in x, y and z directions.

There are 6 equations but 8 unknown quantities, thus it is needed to establish requiring additional conditions. According to [3] the relation between β_2, β_1 and R_{1y}, R_{2y} is described as

$$\frac{R_{1y}}{R_{2y}} = \frac{\sin \beta_2}{\sin \beta_1} \quad (7)$$

Forces $R_A, R_{A'}$ depend on β (if $\beta=0$ then $R_A = R_{A'}$, if $\beta \neq 0$ then $R_A \neq R_{A'}$); α ; X ; a and c ; l and the center of gravity of artillery system. Among the factors mentioned above, β is the most influent on $R_A, R_{A'}$ so that this is considered, others are ignored.

$$\begin{aligned}
 R_A &= \lambda R_{A'}; \quad \lambda \in (0; 1] \\
 \begin{cases} \lambda = 1 & \text{if } \beta = 0 \\ \lambda = 0 & \text{if } \beta = \varepsilon_1 \end{cases} \quad (8)
 \end{aligned}$$

Equations (6)-(8) allow determining 8 unknown quantities.

Axial forces and bending moments on planes KND and KMD of hydraulic support legs:

$$\begin{cases}
 N_i = R_{iz} \cos \theta + R_{ix} \sin \psi \cos \varepsilon + R_{iy} \sin \varepsilon \\
 M_{iKND} = (R_{ix} \cos \delta \cos \theta + R_{iy} \sin \delta \cos \theta - R_{iz} \sin \theta) L \quad (i = 1 \div 2) \\
 M_{iKMD} = (R_{iy} \cos \varepsilon - R_{ix} \sin \psi \sin \varepsilon - R_{iz} \cos \psi \sin \varepsilon) L
 \end{cases} \quad (9)$$

3. DETERMINATION OF THE SUITABLE OPENING ANGLES

According to [9], it is clear that at critical fire angles $\alpha = 0^\circ, \beta = \pm 25^\circ$ the system is most unstable and at $\alpha = 45^\circ, \beta = \pm 25^\circ$ the recoil resistance force is

maximum, therefore. Due to the symmetry, considering only $\alpha = 0^\circ, \beta = 25^\circ$ and $\alpha = 45^\circ, \beta = 25^\circ$. Theoretically, the values of angles ψ, γ can be assigned as:

$$\begin{cases} \psi & (0^\circ \leq \psi < 90^\circ) \\ \gamma & (0^\circ \leq \gamma < 90^\circ) \end{cases} \quad (10)$$

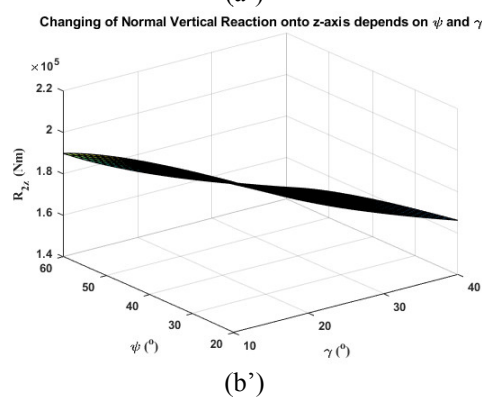
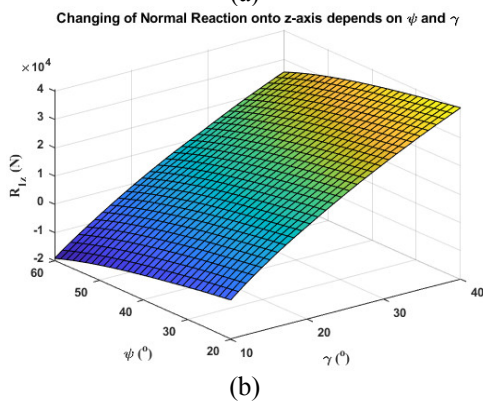
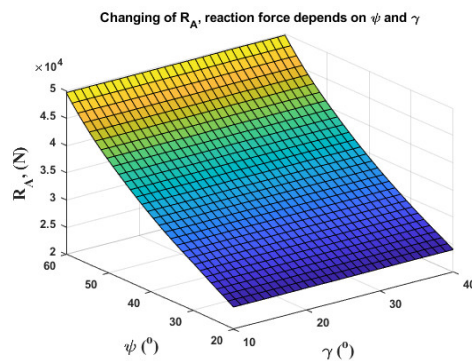
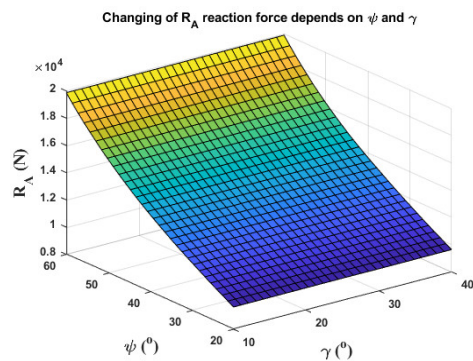
However, in fact the suitable opening angles ψ, γ is constrained by the allowable dimensions and total weight of artillery system, constraint forces and the position of hydraulic support legs connect with frame of KrAZ-255B. In preliminary stage, ψ, γ is determined at range of $\psi = 20^\circ \div 60^\circ, \gamma = 10^\circ \div 40^\circ$. The problem is examined by the Matlab software with inputs are shown in Tab.3.

Table 3. The input parameters.

No.	Notations	Values	Units	No.	Notations	Values	Units
1	X ($\alpha=0^\circ$)	1,25	m	8	ψ	20÷60	°
2	X ($\alpha=45^\circ$)	0,775	m	9	γ	10÷40	°
3	h_{01}	2,785	m	10	P	240345	N
4	h_1	1,719	m	11	P_{lg}	4400000	N
5	e	0,015	m	12	m_r	3029	kg
6	β	25	°	13	$(F_{\max})_{\alpha=0}$	260000	N
7	α	0; 45	°	14	$(F_{\max})_{\alpha=45}$	350000	N

3.1. Results

a. Firing at angles $\alpha = 0^\circ, \beta = 25^\circ$



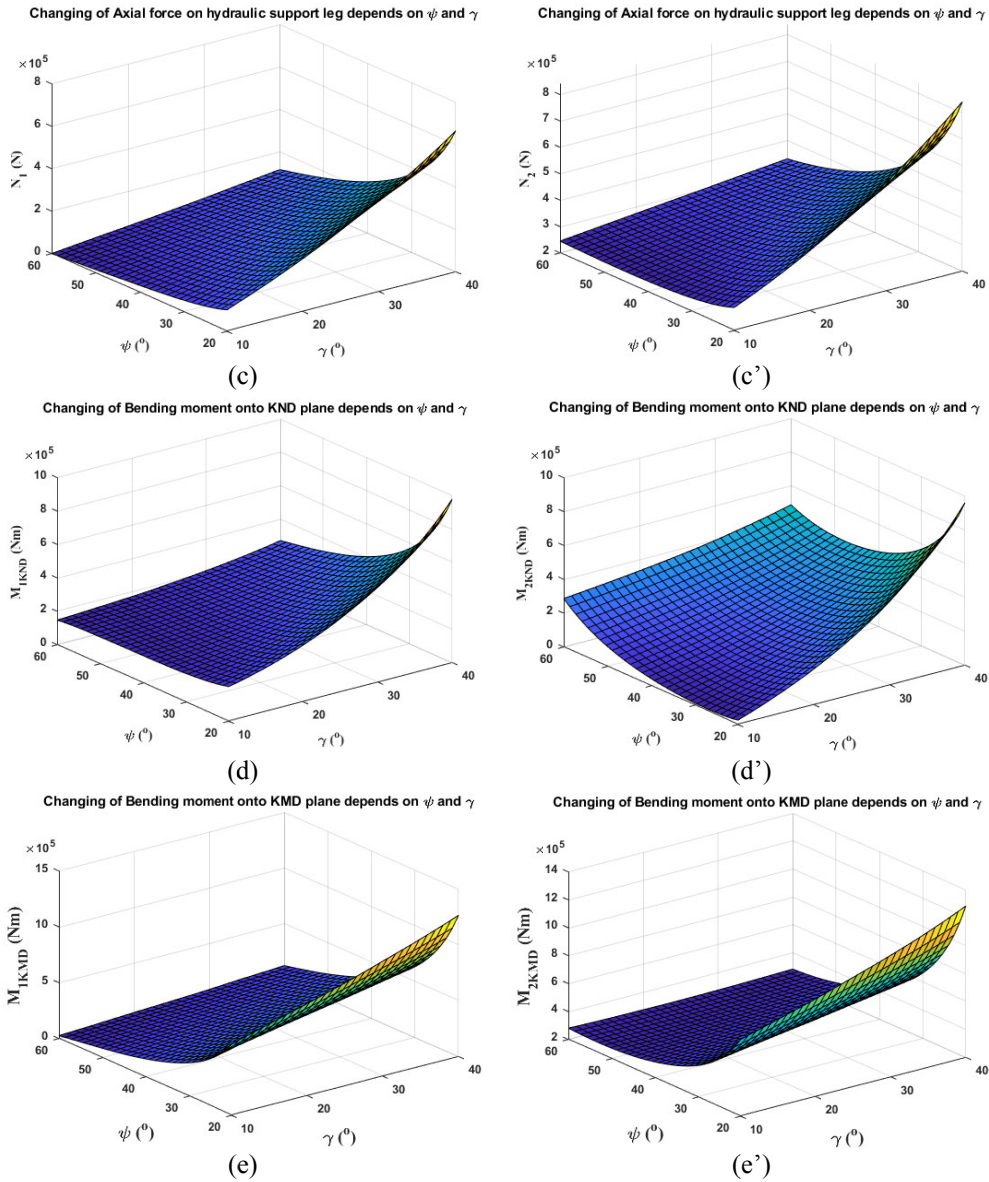
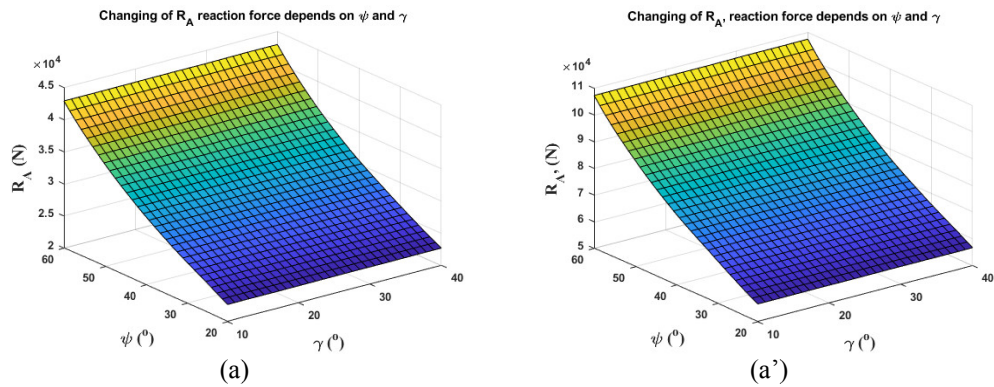


Figure 5. Results of firing at angles $\alpha = 0^0, \beta = 25^0$.

b. Firing at angles $\alpha = 45^0, \beta = 25^0$



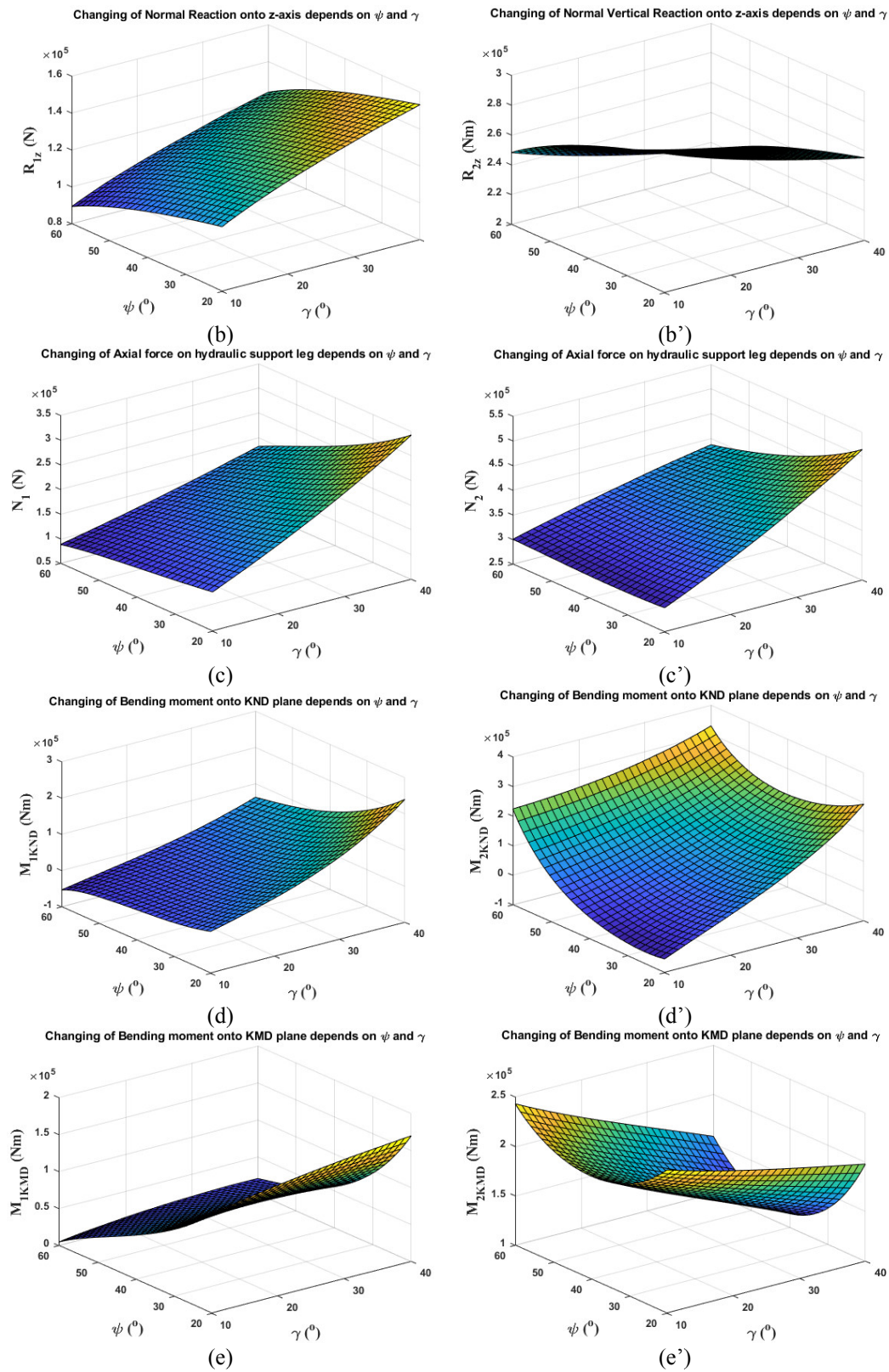


Figure 6. Results of firing at angles $\alpha = 45^\circ$, $\beta = 25^\circ$.

3.2. Discussions

As can be seen from the figure 5 and figure 6 that:

At firing angles $\alpha = 0^0, \beta = 25^0$, axial forces and bending moments of the right hydraulic support leg are larger than the left one. This is because of β_2 is smaller than β_1 so that forces and moments on the right leg is larger than the left leg. Conversely, if $\alpha = 0^0, \beta = -25^0$, axial forces and bending moments of the left hydraulic support leg are larger than the right one.

- When ψ, γ increase then $R_A, R_{A'}$ in figure 5a, figure 5a', figure 6a, figure 6a' and R_{1z} in figure 5b', figure 6b' also increase, hence the artillery system is more static stability. This is interpreted that when ψ, γ increase then the distance from DD' to C and the distance between points D and D' also increase, that results in $R_A, R_{A'}$ and R_{1z} increase.

- When ψ increases then axial force of hydraulic support legs decreases in figure 5c, figure 5c', figure 6c and figure 6c'. This is illustrated by the fact that when ψ increases then the distance from DD' to AA' increases, thus $R_A, R_{A'}$ increase but the axial force in hydraulic support legs decrease.

- When γ increases then axial force of hydraulic support legs also increases in figure 5c, figure 5c', figure 6c, and figure 6c'.

- When ψ, γ increase then bending moments on planes KND and KMD decrease and get the minimum values in the vicinity of $\psi = 40^0, \gamma = 20^0$ as shown in figure 5d, figure 5d', figure 5e, figure 5e', figure 6d, figure 6d', figure 6e, and figure 6e'.

From the analysis above, there are many opening angles of hydraulic support legs meet the given requirements, but the opening angle of hydraulic support legs is chosen at $\gamma = 20^0, \psi = 40^0$. This value is approximately with the values of some self-propelled howitzers such as Archer, Atmos 2000.

The input parameters of self-propelled howitzer M46-130mm at $\gamma = 20^0, \psi = 40^0$ is given in table 4.

Table 4. Results at $\gamma = 20^0, \psi = 40^0$.

No.	Notations	$\alpha = 0^0$	$\alpha = 45^0$	Units
		Values		
1	R_{1z}	9026	119840	N
2	R_{2z}	187510	260870	N
3	R_A	12516	30606	N
4	$R_{A'}$	31291	76514	N
5	N_1	99478	156040	N
6	N_2	305240	351230	N

7	M_{1KND}	192810	8117	N.m
8	M_{2KND}	123790	36578	N.m
9	M_{1KMD}	211450	63270	N.m
10	M_{2KMD}	326880	172660	N.m
11	c	3,711	3,711	m
12	L	1,923	1,923	m

4. CONCLUSIONS

The main conclusions from the research results of the current work can be drawn as follows:

Firstly, this paper researched the problem to bring out the physical model to form forces and bending moments equilibrium equations when putting the static maximum recoil resistance force on artillery system.

Secondly, this work examined the changes of forces and bending moments depends on ψ and γ to satisfy the given requirements. Based on that results the suitable opening angle of hydraulic support legs is selected at $\psi=40^0$ and $\gamma=20^0$.

Thirdly, based on the selected opening angle of hydraulic support legs, giving the table results of forces, moments and dimensions which are the input values for next steps of designing process.

The results of this research are the input parameters to calculate, design and optimize structures of self-propelled artillery.

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TÓM TẮT

XÁC ĐỊNH GÓC MỞ HỢP LÝ CỦA CHÂN CHỐNG THỦY LỰC, PHỤC VỤ THIẾT KẾ TỔ HỢP PHÁO TỰ HÀNH M46-130 mm

Bài báo này nghiên cứu xác định góc mở hợp lý cho chân chống thủy lực của tổ hợp pháo tự hành trên cơ sở tích hợp pháo M46-130mm trên xe quân sự bánh lốp Kraz 255B. Dựa trên kết quả khảo sát sự biến thiên các lực, mô men... tác dụng lên hệ thống trong điều kiện tĩnh khi thay đổi góc mở chân chống thủy lực tại các giá trị góc bắn giới hạn, đã lựa chọn được bộ giá trị phù hợp là $\psi = 40^0$, $\gamma = 20^0$. Từ góc mở đó đã đưa ra được bảng thông số hình học, giá trị lực và mô men tác dụng lên hệ thống. Kết quả này được sử dụng làm bộ thông số đầu vào để tính toán, thiết kế và tối ưu hóa kết cấu cho tổ hợp pháo.

Từ khóa: Tổ hợp pháo tự hành M46-130 mm; Chân chống thủy lực; Góc mở chân chống thủy lực; Điều kiện tĩnh.

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