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BIOMECHANICAL MODEL OF WRESTLING BRIDGE

(Original scientific paper)

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Abstract

This report is an attempt to define the appropriate applied useful approach to study the force structure of athlete in wrestling bridge posture. The kinematic structure and mechanical principles of the proposed mechanical and mathematical model are combined to give the coaches some background information about the structure of the bridge and to define the concept of quantitative evaluation of the existing forces in order to optimize the technical and physical preparation of the athletes. Wrestling bridge is modeled by simple mechanical plane model composed of two half-arches linked via three movable connections (joints) and loaded with external force. The model is considered as absolutely rigid body, and allows based on construction design and the magnitude of the external load forces to quantify the force reactions in all three movable pivotal connections in the horizontal and vertical directions. Initially, it is assumed that the external load acting in the direction of the weight of the athlete and the equations do not include internal forces. Subsequently, in order to get closer to the real wrestling conditions, the model is account that usually the action of the external force is directed at a certain angle. The analysis of the resulting equations indicates that the magnitude of the reactions at the horizontal direction is influenced by the height of the bridge, while the length of the bridge is related to the magnitude and distribution of the vertical support reactions. An important advantage of the proposed model is the ability to quantify the estimated maximum wrestling bridge endurance strength based on data for the bridge kinematics and the static force of the wrestlers' torso and legs.

Keywords: *biomechanics, sports wrestling, modeling, force structure, stability*

INTRODUCTION

Wrestling bridge is a position in which the wrestler is bent back and rests only on feet (a distance between them convenient for each wrestler) and head (to the forehead), hands are free or on the mat (Figure 1). The previous studies treat primarily the medical, biological and biomechanical bridge problems. They point the height as the essential parameter of the bridge configuration, as equals with acrobatic exercises (Angelov (Ангелов), 2013). This is insufficient, since in the implementation of a large number of wrestling grips and in defense of them, wrestling bridge is subject of large force load: the force of its own weight and the opponent's weight, the inertial forces, additional applied force from opponents and others (Stancev (Станчев), 1999; Sergiev (Сергиев), 2000). Obviously, the state of wrestling bridge depends too much of its force sustainability.

Given the importance of this sports skill in both technique and style of the wrestling, there is an obvious need for a thorough examination of this sports technique, continuously improve the training methodology and produce of quantitative criteria for assessing the quality of implementation and the training process. Creating appropriate biomechanical and mathematical models to quantify the force structure in the wrestling bridge posture would have considerable practical benefit and would contribute to the further development of the wrestling sport.

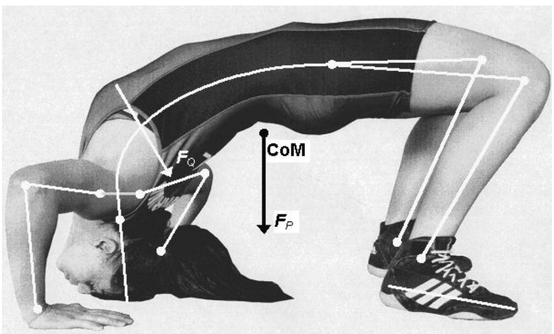

Figure 1. An athlete in position "wrestling bridge", acting forces and basic biomechanical structures

The purpose of this work is to develop a biomechanical and mathematical model to quantify the force structure of wrestling bridge at a certain bridge configuration and external load.

METHODS

For purposes of this study, photos of athlete in position "wrestling bridge" have been used, (see Figure 1). It should be noted that from the biomechanical aspect this position is a closed kinematical chain. Typical of these kinematical connections is that the movement in one segment causes movement in the other nodes of the chain. This type of chain unites moves, fixes joints (which in this case is useful for the sustainability of the bridge) and allows remote control and precision of the movement.

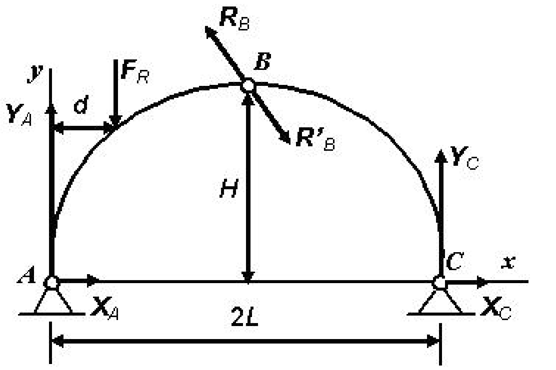

Figure 2. Mechanical model of "wrestling bridge" in the sagittal plane

According to Araciski (Аракчийски), (2013) the "wrestling bridge" can be represented by a simplified version of a mechanical model in the sagittal plane (Figure 2), representing ***ABC*** arch of two parts, connected with three movable connections (joints) and loaded with external force. On Figure 2 are also identified the necessary dimensions, involved in the equations for the forces.

The model allows us to quantitatively determine the force reactions in moving joints ***A***, ***B***, and ***C***. In this way you can reach important conclusions about the influence of the bridge parameters on its configuration stability and take decisions on pedagogical aspect.

RESULTS

In solving similar tasks, usually the approach is through the release of connections, replacing them with their joint force reactions that subsequently are decomposed into two components in the direction of the coordinate axes. The design of the model, the balance of which we study, consists of two parts - a half-arch ***AB*** and the half-arch ***BC***, connected by means of hinge ***B***. The structure is in equilibrium under the action of following forces: external forces - the net force of load F_R and force reactions R_A and R_C of the hinges ***A*** and ***C*** and internal forces R_B and $R'_B = - R_B$, which are the interaction forces between the two half-arches, transmitted by means the hinge ***B***. We initially assume that the force load F_Q (see. Figure 1), applied additionally on the bridge, operates in the direction of the competitors weight force F_P, i.e.

$F_R = F_P + F_Q$ (1)

If denoted by X_A, Y_A and X_C, Y_C the reactions projections R_A and R_C on the coordinate axes, the equations of equilibrium of the entire construction of the arch with three hinges ABC, seen as absolutely rigid body in a plain system of forces will have the form:

$\sum X = X_A + X_C = 0$ (2)

$\sum Y = Y_A + Y_C - F_R = 0$ (3)

$\sum mom_A F = - F_R d + Y_C 2L = 0$ (4)

where: ΣX is the sum of the reactions' projections on the horizontal axis;

ΣY is the sum of the forces' projections on the vertical axis;

$\Sigma mom_A F$ is the amount of the torques to point A;

d and 2L are the action arms, respectively, of the forces F_R and Y_C.

The internal forces are not included in these equations. From equation (4) we have

$Y_C = F_R d / 2L$(5) and then from equation (3) we find

$Y_A = F_R - Y_C = (1 - d / 2L) F_R$ (6)

The conclusion from equation (2) is that

$X_A = - X_C$ (7)

In order to find each X_A, X_C, as well as R_B, the balance of one part of the bridge is considered. The layout of acting forces is shown on Figure 3.

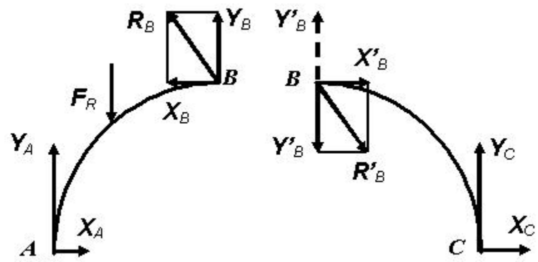

Figure 3. Components of the model structure of Figure 2

Typically we analyze the part of the system where the number of acting forces is smaller. In this case it would be right half-arch ***BC***. To compose its balance equations, assuming that the projections X'_B and Y'_B are initially positive (dotted line of component Y'_B in Figure 3):

$\sum X = X'_B + X_C = 0$ (8)

$\sum Y = Y'_B + Y_C = 0$ (9)

$\sum mom_C F = - Y'_B L - X'_B H = 0$ (10) where:

$\Sigma mom_C F$ is the amount of the torques to point C;

H is the bridge height.

From equations (8) to (10) and (5) we define

$Y'_B = - Y_C = - F_R d / 2L$ (11)

$X'_B = - Y'_B L / H = F_R d / 2H$ (12)

$X_C = - X'_B = - F_R d / 2H$ (13)and respectively

$X_A = - X_C = - F_R d / 2H$ (14)

According to expression (11), the actual direction of the component Y'_B is indicated in Figure 3 with a solid line. Also, according to (7), the actual direction of X_A is opposite to the X_C and is directed outwards from the bridge.

DISCUSSION AND CONCLUSIONS

Let's take a closer look at the results. According to expression (5), the vertical reaction Y_C in point ***C*** is directly proportional to the torque generated of the vertical component of the bridge load resultant force ($F_R\, d$), and inversely proportional to the distance between the bridges supports (**2*L***). This reaction is counteracting of the normal pressure on the support, which directly determines the friction force ***Ffr***. Friction forces in two supporting elements oppose the horizontal component of the support reactions X_A and X_C and thus have a stabilizing effect on the sustainability of the bridge configuration. In turn, since the size of X_A and X_C is inversely proportional to the height of the bridge ***H***, with an increase in the height dimension increases the bridge resistance.

In practice, the direction of the bridge load resultant vector F_R is not always only in the vertical direction and may conclude an angle ***φ*** from the horizontal direction. This situation is shown in Figure 4. In this case, the force F_R is decomposed into two components, in horizontal and vertical directions, respectively F_{Rx} and F_{Ry}. For their size we get

$F_{Rx} = F_Q \cos\varphi$ (15)

$F_{Ry} = F_P + F_Q \sin\varphi$(16) where:

F_P is the competitors' weight force;

F_Q is a load force.

The force F_R is a result of the F_P and F_Q vector sum and its size is defined as

$F_R = \sqrt{F_R^{\;2} + F_R^{\;2}}$ (17)

To calculate the force reactions and torques, it is necessary both components of the resultant load force to be replaced in the equations of the model. So force F_R must be replaced with F_{Ry}, while F_{Rx} will participate as a new force in the equations. Then we will have

$Y_C = F_{Ry}\, d / 2L$ (18)

$Y_A = F_{Ry} - Y_C = (1 - d / 2L)\, F_{Ry}$ (19)

$\sum X = X_A + X_C + F_{Rx} = 0$ (20)

From equation (20)

$X_A = - X_C - F_{Rx}$ (21)

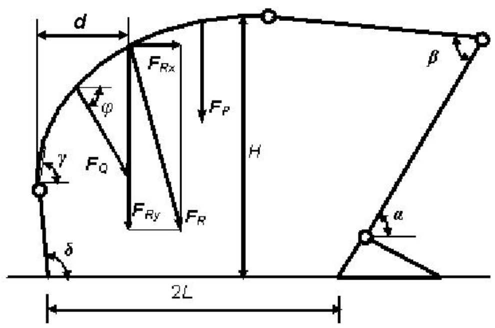

Figure 4. Wrestling bridge configuration model, including major joint nodes and acting forces

Similarly revise equations (8, 9 and 10)

$\sum X = X'_B + X_C + F_{Rx} = 0$ (22)

$\sum Y = Y'_B + Y_C = 0$ (23)

$\sum mom_C\, F = - Y'_B L - X'_B H = 0$ (24) where:

$\Sigma\, mom_C\, F$ is the amount of the torques to point C;

H is the height of the bridge.

From equations (22) to (24) and (18) we define

$Y'_B = - Y_C = - F_{Ry}\, d / 2L$ (25)

$X'_B = - Y'_B L / H = F_{Ry}\, d / 2H$ (26)

$X_C = - X'_B - F_{Rx} = - F_{Ry}\, d / 2H - F_{Rx}$ (27)

The configuration of the bridge is determined by its parameters - height ***H***, length **2*L***, angle ***α*** between the mechanical axis of the lower leg and the horizontal axis, angle ***β*** between the mechanical axis of the lower leg and thigh, angle ***γ*** between the horizontal axis and tangent to the back, angle ***δ*** between the horizontal axis and the axis of the head. Configuration sustainability consists in maintaining these parameters within certain limits. Key role for this purpose have powerful wrestlers muscles of the torso and legs.

In conclusion, let us use typical values of the parameters for category 82 kg classic style to have an idea about the magnitude of the calculated force reactions:

H = 0.39 m

2L = 0.71 m

d = 2L/4 = 0.18 m

φ = 60 градуса

F_P = 82 kg

F_Q = 82 kg

Substituting values in the equations gives the following results:

X_A = 35 kg

X_C = 76 kg

Y_A = 115 kg

Y_C = 38 kg

The data obtained show that in the horizontal direction support ***C*** has more than twice as large loads, and the vertical support reaction in the support ***A*** is three times larger than the force in point ***C***. By using the proposed model and the calculation of the relevant joint reactions, an overall optimization of the wrestling bridge configuration can be achieved. This includes determining the force efforts of the responsible muscle groups, coordination of configuration against category, anthropometry and the individual features of the competitors, simulation of different options to avoid a bridge, or overcoming a bridge, and compiling exercises for general and special wrestlers' training.

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