Design, Modelling and Building of Geotechnical Centrifuge from Nueva Granada Military University

PAHOLA PORRAS [(1)], G.L VARGAS-FONSECA [(2)], O.J REYES-ORTIZ [(3)]

(1) nelcy.porras@unimilitar.edu.co
(2) german.vargas@unimilitar.edu.co
(3) Oscar.reyes@unimilitar.edu.co

Geothecnical Group, Civil program
Nueva Granada Military University, UMNG
Bogotá, Colombia

Design, Modelling and Building of Geotechnical Centrifuge from Nueva Granada Military University

ABSTRACT

The deformation and stress in a civil construction can be simulated in small scale by geotechnical centrifuge equipment. To evaluate the geotechnical events the model has to be subjected to acceleration field between 150 - 300 Earth's gravity. The Geotechnical group of Nueva Granada Military University designed a project whose the main objective is design, modelling and building a geotechnical centrifuge with a specification as effective spin radius, mass and volume of specimen over the swing, maximum acceleration, par and others. These aspect are described in this paper.

The first phase to concerns is the background of geotechnical centrifuge mechanical design and the scale laws, the second phase is the design and simulation in SolidWorks of stress and deformation in each assembly of the geotechnical centrifuge, which was 2.4 meters effective radium, 200 g of maximum acceleration and 500Kg weight over the swing. Finally, the last phase is the building and verification of the final design to take into account the maintenance and useful life of the new machine.

Keywords:
Centrifuge Acceleration; Geotechnical Centrifuge; Modelling; Simulation and Soil

I. INTRODUCTION

The analysis of geotechnical problems has been studying since the last decades in different areas of engineering. The need of understand the building, natural hazard and behavior of elements in construction industries has been overcome by small model with a scale consideration in geotechnical centrifuge [1].

Early geotechnical centrifuges started with Edouard Phillips, who recognition the need of a centrifuge machine to evaluated model with similarity of stress and materials between the model and the prototype [1,2] .Then the dynamic effects and the scale laws are described [3,4,5].

On the next years different models of centrifuges were designed and built. Besides design, two main categories are: beam centrifuges that are composed by beam as an arm, which in the end has an assembled swing where the model is located [6], the other category is drum centrifuges [7]. This type of centrifuges are composed by a simple drum that inside of it the model took place [8, 9]. Both of them have size, maximum acceleration, model mass defined by user [10].

The Geotechnical Group at the Nueva Granada Military University designed, modelled and it is building a Geotechnical centrifuge type beam, with a central spindle supporting a pair of parallel arms with 2.4 meters radio, maximum acceleration 200 Earth gravity and 500 Kg mass of the model [11].

II. MECHANICAL DESIGN

To design the geotechnical centrifuge of Geotechnical group from Military University the main characteristics on table 1:

TABLE 1. DESIGN PARAMETERS

Maximum acceleration	200g
Effective diameter	2.4 m
Maximum load specimen	500Kg

Beam geotechnical centrifuge is composed by: two arms of pipe, a shaft of 4341 steel, two swing A572 steel of 1 m x 1 m x 90, a structure steel base to avoid vibration from movement, besides a box of aluminum to keep instrumentation and data logger on the top. Lastly the bunker where the machine will be installed is around 8 meter diameter and 4 meter high.

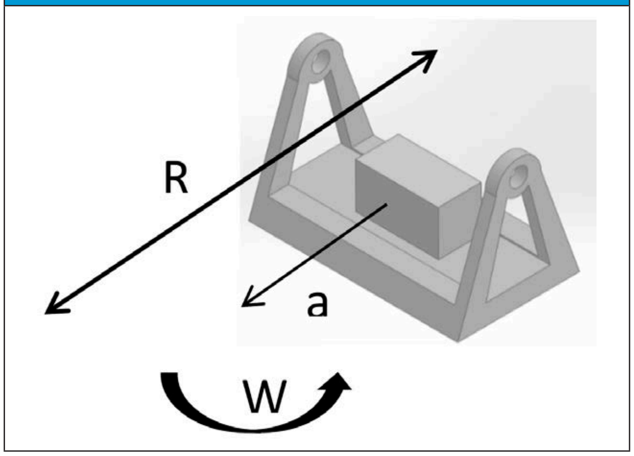
A. Kinematic description

First at all to design the arms and the rotational shaft the maximum acceleration field has to be known (1).

$$a = w^2 R = Ng \qquad (1)$$

Where a: centrifuge acceleration; w: rotational speed; R: radius from rotational axis to center of mass in the conteiner; N: scale factor; g: earth gravity.

Fig. 1. Diagram of centrifuge acceleration. Source: Authors



B. Strutural design Kinematic description

To analyze the geotechnical centrifuge as a static structure to get the forces and the moment of inertia a diagram was drawn and is showed in Fig 2. Where the forces over the model were represented.

Where a_c: centrifuge acceleration; a_t: tangential acceleration; F_t: tangential force; F_n: normal force. Then the movement diagram was sketched in Fig 3. To take in account the dynamic forces in the specimen over the swing.

On the horizontal plane the force is F_n, which is composed by mass of the specimen and the a_n that is zero when the movement start as in (2). On another plane the vertical force is F_t , which is mass of the specimen and the a_t that is defined by the angular acceleration show in (3). Additionally the moment force or torque M_p is well-defined by total inertia I_t and the angular acceleration $\propto$ (4).

Fig. 2. Diagram of forces of model in a centrifuge machine. Source: Authors

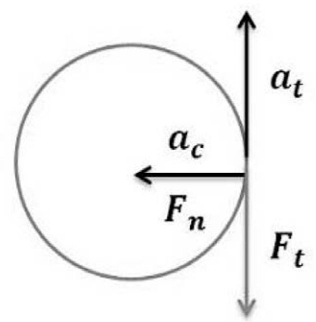
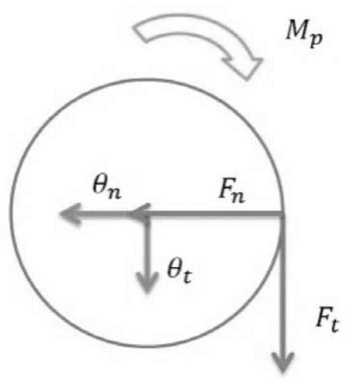


Fig. 3. Diagram of forces and moment of model. Source: Authors



Horizontal force

$$\Sigma F_n = m.\, a_n \quad (2)$$

Vertical force

$$\Sigma F_t = m.\, a_t \quad (3)$$

Moment force

$$\Sigma M_p = I_t.\propto \quad (4)$$

A. Torque with 1 earth's gravity acceleration:

When the maquine start the acceleration is 1g, then from (2):

$$\Sigma F_n = m.\, a_n = m.r.w^2 = 0 \quad (5)$$

Equation 5 is 0 because at the beginning of the test the angular velocity is none.

From (3):

$$\Sigma F_t = m.\, a_t = m.\propto.\, r = 0 \quad (6)$$

$$-\theta_t + F_t = m.\propto.r = -\theta_t + 1600\ Kg = 1600\ \text{Kg}.\ (1).(\propto)$$

From (4):

$$M_p = I_t.\propto = \theta_t\,(r) = m.\ r^2.\propto \quad (7)$$

Solving θ_t from (7):

$$\theta_t = \frac{mr^2a}{r} = mra = \frac{1600\ Kg}{9.8m/s^2}.\ 2.4m.\ a \quad (8)$$

Then, replacing (8) in (7) so:

$$a = 0{,}567\ rad/s^2$$

And finally from (4):

$$\Sigma M_p = I_t.\propto = I\,(I_{beam} + I_{swing})\ .\propto \quad (9)$$

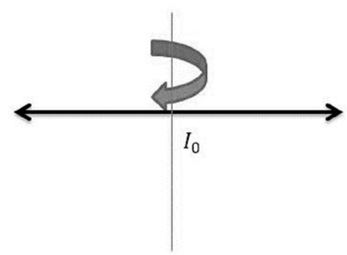
The next step is calculate the inertial moment so:

The inertial moment of a beam, which is spinning around its mass center is showed in Fig. 4 and (9):

$$I_0 = \frac{1}{12} mL^2 \quad (9)$$

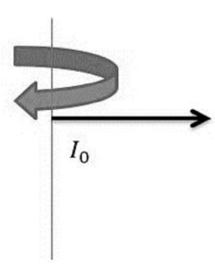
$$I_0 = \frac{1}{12}(100\ Kg)\ (2.4m)^2 = 48Kgm^2 \quad (10)$$

Fig. 4. Diagram of beam inertial moment. Source: Authors



The inertial moment of a swing is defined by (11,12) and the draft is showed in Fig 6.

Fig. 5. Diagram of swing inertial moment. Source: Authors



$$I_0 = mr^2 \quad (11)$$

$$I_0 = (1500\ Kg)(1.2m)^2 = 2160Kgm^2 \quad (12)$$

The total mass of 1500Kg assuming that 500Kg of specimen, 200Kg of joins supports between the swing and the beam that in this particular case is a pipe to reduce the mass. Besides, 600Kg of swing steel and 200Kg of steel box.

Finally the total inertia is:

$$I_t = 48\ Kgm^2 + 2160\ Kgm^2 = 2208\ Kgm^2 \quad (13)$$

Now that the total inertia is done, the moment force from (9) is:

$$M_{p(1g)} = I_{t(1g)} \cdot \alpha_{1g} = 2160Kgm^2 \cdot 0{,}6\ rad/s^2 \approx 1324N.m \quad (14)$$

B. Torque with 200 earth's gravity acceleration:

The maximum acceleration of the geotechnical centrifuge is going to take around 200g, to calculate the high torque from (15 and 16):

$$\alpha_{200g} = 1.09\ rad/s^2 \quad (15)$$

$$M_{p(200g)} = I_{t(200g)} \cdot \alpha_{200g} = 2160Kgm^2 \cdot 1.09\ rad/s^2 = 2354N.m \quad (16)$$

C. Motor Selection:

Having a maximum torque of 2354N.m, so the velocity was calculated by (17)

$$a_c\left(\frac{m}{s^2}\right) = w^2\left(\frac{rad^2}{s}\right) . r(m) \rightarrow w \approx 35\ rad/s \quad (17)$$

Therefore, the angular velocity is 340rpm. Then the motor power is considered by (18)

$$Power = \frac{T[N.m].\ n.\ rpm}{9550} = \frac{2354.340}{9550} = 83Kw$$

D. Shaft diameter:

To estimate the shaft diameter the (18) was used:

$$D = \left[\frac{32N}{\pi}\sqrt{\left[\frac{K_t M}{s,n}\right]^2 + \frac{3}{4}\left[\frac{T}{s_y}\right]^2}^{\,1}\right]^{1/3} \quad (18)$$

Where K_t: stress concentrator and it is 3 because is flexion. N: design factor and is 4 due to impact conditions, M: bending momentum, T : torque, $S'n$: limit fatigue strength, S_y: limit yield strength.

A. S'n is calculated by (19):

$$S'n = S_n\,(C_m)\,(C_{st})\,(C_r)\,(C_s) \approx 193MN/m^2 \quad (19)$$

B. M is determinated by (20):

$$M = mrlw^2 = 1040062.5\ N.m \quad (20)$$

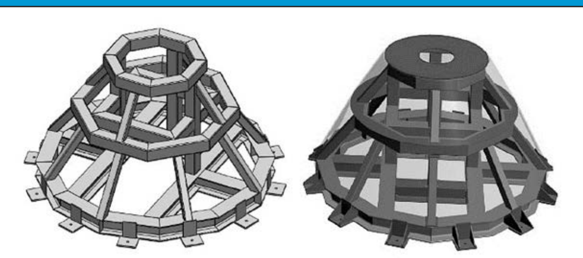
III. SOLID WORKS DESIGN

To close with the main characteristics of design the geotechnical centrifuge was designed and simulated by small assemblies.

A. Base assembly:

In Fig 6. the base was designed with 3 m of diameter and 2.2m large. On the bottom the base was structured by HEA 200 structural steel, then the next two octagons and the rest of the structure was structural profile 150 x 150 x 4 mm and 100 x 100 x 4 mm.

Fig. 6. Geotehcnical centrifuge base. Source: Authors



B. Swing assembly:

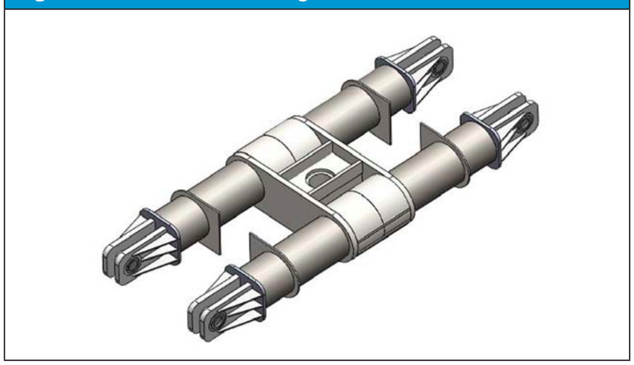
The two swing of the geotechnical centrifuge were designed exactly the same materials and specifications. The initial requirement from civil engineers was: in the swing a square box of 90cm x 90cm x 70cm has to be installed. The A572 steel was selected to keep the 3.5 safety factor which is a critical variable in dynamical machines. To close the design of the swing is showed in Fig 7.

C. Arms assembly:

As far as it can see, the beam assembly is manufactured with 2 pipe around 2 m large, a subassembly that swing support where the swing are joined through a bolt, described in Fig 8.

Fig. 7. Geotehcnical centrifuge swing. Source: Authors

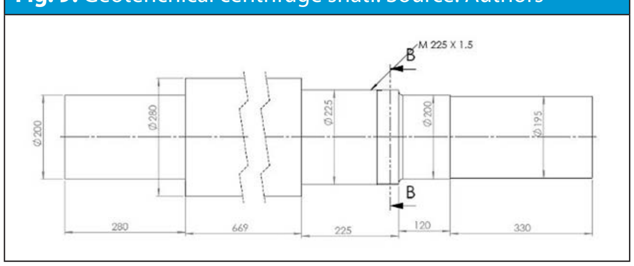
Fig. 8. Geotehcnical centrifuge arms. Source: Authors



D. Shaft assembly:

Previously mentioned the diameter of shaft is 280mm then was designed and simulated on the Fig 9 the measures are drawn.

Fig. 9. Geotehcnical centrifuge shatf. Source: Authors



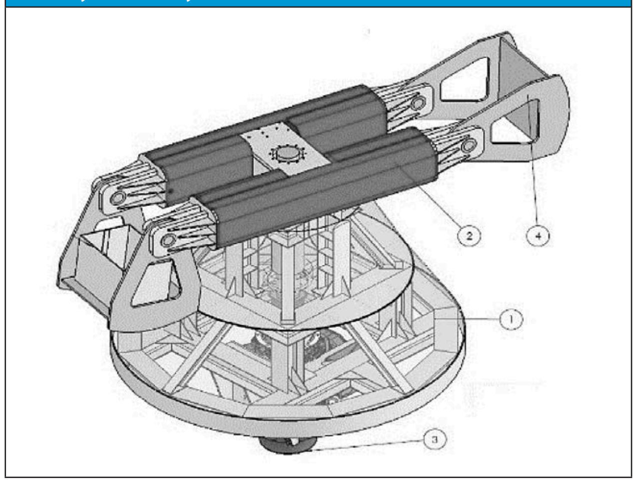
E. Motor assembly:

The motor had to be assembled on the bottom of the machine to obtain a better stability and avoid vibration. For that reason, the reducer and the motor were directly assembled to the shaft. The motor selected was 90Kw and re reduction relation was 5:1.

F. Total assembly:

In Fig 10 a whole assembly is detailed as number 1 is the base assembly before mentioned, number 2 is the beam assembly that are the arms of the machine, then 3 is the motor and lastly number 4 are the swing.

Fig. 10. Geotehcnical centrifuge from Nueva Granada Military University. Source: Authors



Furthermore every assembly was simulated with VonMisses and safety factor to keep 3.5 scale, also de unitary deformations were taken into account.

IV. RESULTS

As a result of the mechanical design. The first assembly to build was base structure and took 3 weeks in production. Besides, destructive test were done to check the quality of weld in each join. In Fig 11. The structural steel of base with beam of H shape on the bottom.

Fig. 11. Base under construction. Source: Authors

The rest of the structure was fabricated with square structural steel and is exposed in Fig 12. To confirm the quality of weld, inks penetrant were applied over each junction. This type of test is used to detect where is no- continue the weld cordon. Three types of ink were selected, firstly a cleaner liquid to take off all particles that are no part of the cord weld Secondly, a white red spray is applied in each juncture, the purpose of this liquid is to penetrate in the whole weld. As a final point after few minutes a revelator is spread out. Then the incorrect weld are represented by red point.

Fig. 12. Base concluded. Source: Authors

Another test made to base was a sandblast procedure that consists in a sand with high velocity to clean the surface. Furthermore, the base was painted with anti-rust enamel.

Nowadays, the swing assembly has been done. Fig 13 show the early parts under building.

Fig. 13. Swing side. Source: Authors

In a near future the geotechnical centrifuge will be assembled at Nueva Granada Military University Campus located in Cajica.

V . CONCLUSION

The geotechnical centrifuge helps the Civil engineers to understand the geotechnical events as a natural hazards, soil structure interaction.

A well-organized analyze in kinematic and dynamic forces assistance to design in a better ways a mechanical design.

Modelling in a special software for engineers like SolidWorks help to avoid possible break out as a consequence of fatigue.

Simulation shows the main deformation and supports to redesign when it necessary.

The synergy between both areas of engineering such as civil and mechatronics benefit a lot to solve a massive problem.

ACKNOWLEDGMENT

The authors would like to thank Nueva Granada Military University and the Vice-Rectory of Research for the economic support with IMP-ING-1575 project.

REFERENCES

[1] R. Taylor, Geotechnical centrifuge technology. London: Blackie Academic & Professional, 1995.

[2] C. Ng, 'The state-of-the-art centrifuge modelling of geotechnical problems at HKUST', Journal of Zhejiang University SCIENCE A, vol. 15, no. 1, pp. 1-21, 2014.

[3] R. Shen, C. Wong and L. Tan, Geothecnical centrigue userÂ's manual, 2nd ed. Singapure: department of civil and viromental engineering, 2011, pp. 7-20.

[4] d. Wilson, R. Boulanger, B. Hamann, B. Jeremic, B. Kutter, K. Ma, C. Santamaria, K. Sprott, S. Velinky, G. Weber and S. Yoo, 'THE NEES GEOTECHNICAL CENTRIFUGE AT UC DAVIS', in 13th World Conference on Earthquake Engineering, Vancouver, canada, 2015, pp. 1-5.

[5] P. Bryden, 'Centrifuge modelling of flexible buried pipes', Master of Science in engineering, University of new brunswick, 1994.

[6] D. Kim, N. Kim, Y. Choo and G. Cho, 'A newly developed state-of- the-art geotechnical centrifuge in Korea', KSCE Journal of Civil Engineering, vol. 17, no. 1, pp. 77-84, 2012.

[7] A. Schofield, 'Cambridge Geotechnical Centrifuge Operations', GÃ©otechnique, vol. 30, no. 3, pp. 227-268, 1980.

[8] N. Solomon, Centrifuge modeling, intelligent geotechnical systems and reliability-based design. Washington, D.C.: National Academy Press, 1997.

[9] T. Kimura, Geotechnical centrifuge model testing. [Tokyo?]: Japanese Society of Soil Mechanics and Foundation Engineering, 1984.

[10] 'Geotechnical centrifuge modelling at the University of Western Australia', International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts, vol. 28, no. 5, p. 311, 1991.

[11] J. Camaho-Tauta, O. Reyes-Ortiz and J. Santos, 'Evaluation of the frequency effects on the shear wave velocity of saturated sands', Lisboa,Portugal, 2012.