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SUPPLEMENTARY ONLINE MATERIAL FOR

Three-dimensional elasto-plastic soil modelling and analysis of sauropod tracks

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Supplementary Online Material

Through this SOM the methodology and work before the main work will be discussed. These works were carried out previously and collect sufficient data and analysis to the opinion of the authors to provide a solid basis for the main job.

Authors began the modeling of sauropods ichnites over 10 years ago. Results of these works were submitted to the "III Jornadas sobre Paleontología de Dinosaurios y su Entorno" ("Third Conference on Palaeontology Dinosaurs and its Environment" venue placed on Salas de los Infantes, Burgos, Spain, 16−18 September 2004).

Such paper was entitled "Las deformaciones producidas en los sedimentos por el paso de grandes dinosaurios: el caso del yacimiento de saurópodos de Miraflores I, Fuentes de Magaña (Soria, España) [Deformations in sediments produced by the footstep of large dinosaurs: the study of the Miraflores sauropod tracksite, Fuentes de Magaña (Soria, Spain)]".

It shows how modeling work began with an analytical model that reproduced the extrusion of a deformable layer between two rigid.

Circular footprint, under radial symmetry efforts was supposed. It is shown, in Figure 1, tension equilibrium conditions when a radial extrusion occurs. The following nomenclature has been used.

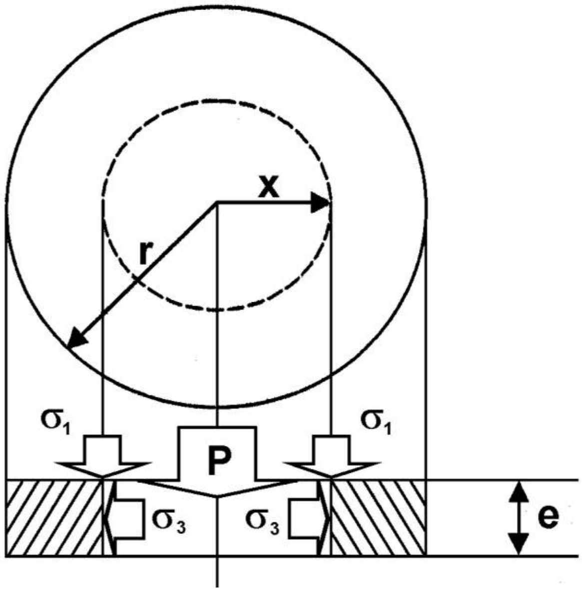


Figure 1.

r = footprint radius (m)

e = thickness of the extruded layer (m)

c_u = non-drained cohesion or resistance of the layer (t/m2)

σ_1,σ_2 = principal stresses at a distance x from the center of the footprint

P = total load necessary for the radial extrusion (t)

σ_3 = stress required to extrude the ground between x and r.

The stress σ_3 must prevail over the cohesive strength c_u at the annulus border in contact with the upper and lower sliding surfaces:

$$\sigma_3 = 2 \cdot c_u \cdot \pi \cdot \left(r^2 - x^2\right) / 2 \cdot e \cdot x \cdot \pi = c_u \cdot \left(r^2 - x^2\right) / \cdot e \cdot x$$

The vertical stress σ_1 to overcome horizontal resistance σ_3 in a purely cohesive soil is:

$$\sigma_1 = \sigma_3 + 2 \cdot c_u = c_u \left(\left(r^2 / e \cdot x\right) - \left(x / e\right) + 2\right)$$

Total weight W required to complete circular extrusion on the footprint of radius r is:

$$W = \int_{x=0}^{x=1} 2 \cdot \pi \cdot \sigma_1 \cdot x \cdot dx = 2 \cdot \pi \cdot c_u \cdot r^2 \cdot \left(2 \cdot r / 3 \cdot e + 1\right) \qquad (1)$$

The weight obtained corresponds to the load of a single limb.

Thus, applying formula (1) for footprints with radius between 30 and 60 cm are obtained the weights per limb showed in Table 1.

Values of c_u are between 3 and 5 t/m2 (typical clay soils).

Thickness *e* is 0.15 m as in the case studied in the paper.

Table 1, also includes the total animal weights, calculated from the hypothesis of ambling movement and a weight distribution between the foot (70 weight%) and hand (30% weight).

Radius (m)	W/limb (t)	Wtotal (t)	W/limb (t)	Wtotal (t)	W/limb (t)	Wtotal (t)
	$c_u = 3$ (t/m^2)		$c_u = 4$ (t/m^2)		$c_u = 5$ (t/m^2)	
0.30	4.0	5.7	5.3	7.5	6.6	9.4
0.35	5.9	8.4	7.9	11.2	9.8	14
0.40	8.4	12.0	11.2	16.0	14	19.9
0.50	15.2	21.7	20.2	28.9	25.3	36.2
0.60	24.9	35.5	33.2	47.4	41.5	59.2

Table 1 Weights per limb for circular footprint with radius between 30 and 60 cm and values of c_u between 3 and 5 t/m^2.

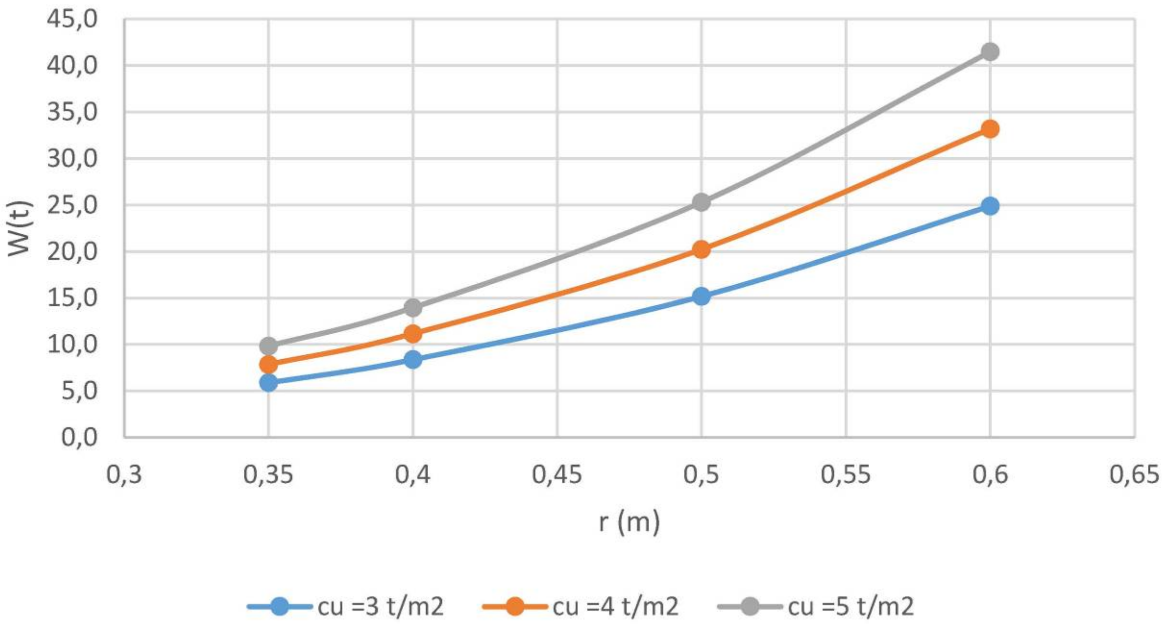


Figure 2. Showing the relationship between weight per limb and radius of the footprint for some values of cu.

The paper also included modeling by the finite element method. These modeling was axial symmetric, which forced to consider the hypothesis of a circular footprint. As in the case of the previous analytical model, were used parameters which showed short term behavior under total stress.

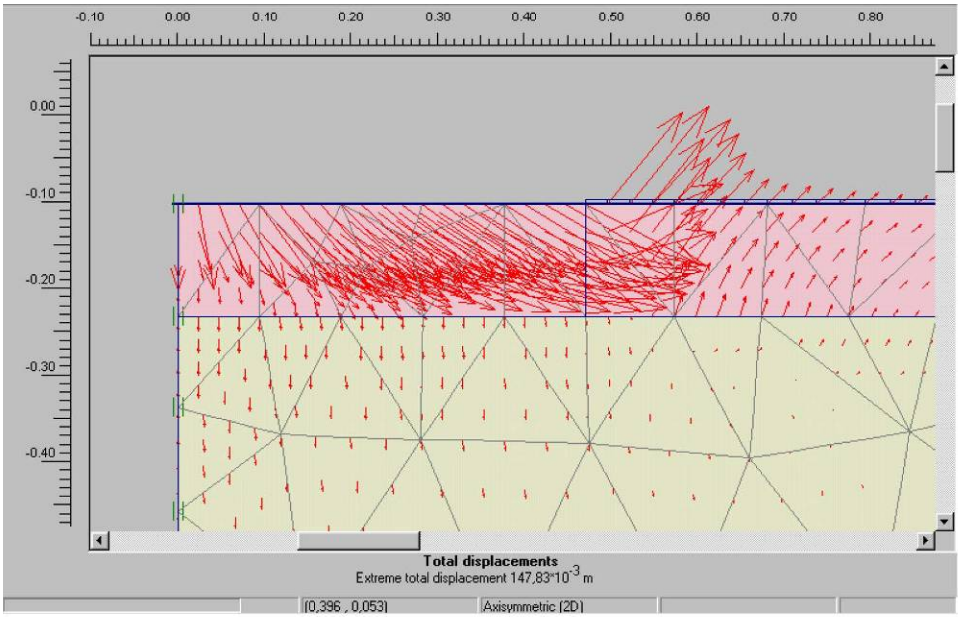
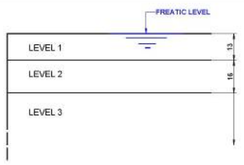
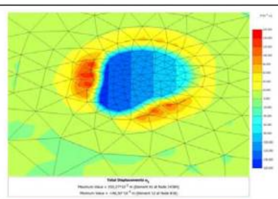
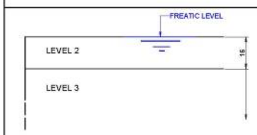
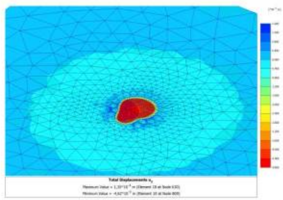
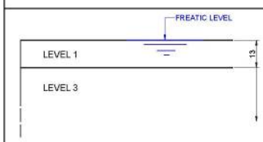
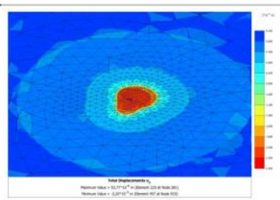


Figure 3. Showing the displacements in the extruded layer obtained with the axial symmetric finite element model.

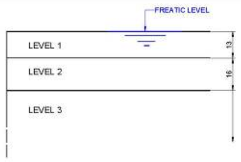
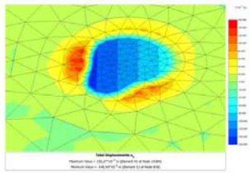
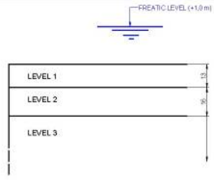
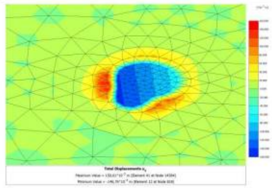
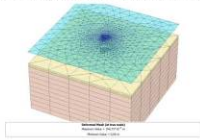
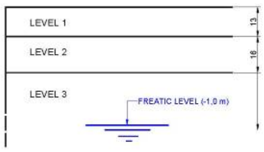
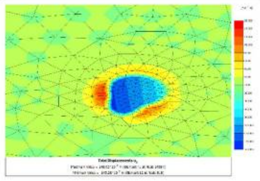
Current modeling has improved others due to its three-dimensional type and shows the real footprint shape. Moreover the current modeling shows similar deformational parameters but different (but equivalent) resistant parameters, due to introduction of undrained effective stress behavior to control the variation pore pressure considering, among other factors, soil permeability.

Taking in account these items, calculations have been obtained following three steps:

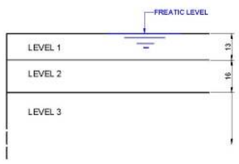
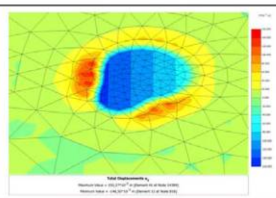
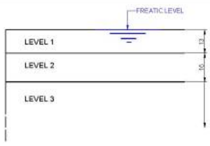
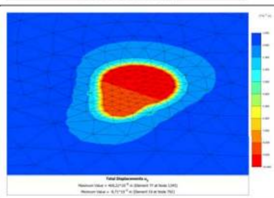
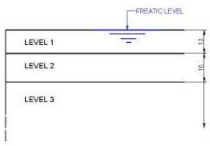
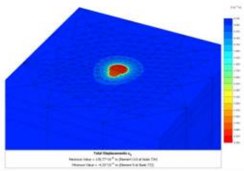
• Presence or no of different soil levels (Figure 4).

LEVEL SCHEME	VERTICAL DISPLACEMENTS (Uy)	MAXIMUM DISPLACEMENTS (mm)	COMMENTS
		u_y (+) = 100-120 mm u_y (-) = 100-120 mm	Reached modeling shown in paper.
		u_y (+) = 1-2 mm u_y (-) = 4-5 mm	Very small extrusion. Poor footprint depth. Rims almost inexistent.
		u_y (+) = 0 mm u_y (-) = 2-3 mm	There is no extrusion. Very few footprint depth. There are not rims.

• Position the water table from the surface of the soil (Figure 5).

LEVEL SCHEME	VERTICAL DISPLACEMENTS (Uy)	MAXIMUM DISPLACEMENTS (mm)	COMMENTS
		u_y (+) = 100-120 mm u_y (-) = 100-120 mm	Reached modeling shown in paper.
		u_y (+) = 110-130 mm u_y (-) = 100-120 mm	Changes almost inexistent. 
		u_y (+) =100-110 mm u_y (-) = 100-110 mm	Almost no changes. Maybe on the contrary than others

• Influence of the footprint size (Figure 6).

LEVEL SCHEME	VERTICAL DISPLACEMENTS (Uy)	MAXIMUM DISPLACEMENTS (mm)	COMMENTS
		u_y (+) = 100-120 mm u_y (-) = 100-120 mm	Final modeling shown in the paper.
 Same pressure than big footprint ⇒ F = 5 kN		u_y (+) = 0 mm u_y (-) = 8-10 mm	Footprint depth decreasing No rims are significant due to a small extrusion.
 80% big footprint pressure ⇒ F = 4 kN		u_y (+) = 0 mm u_y (-) = 4-5 mm	Footprint depth decreasing No rims are significant due to a small extrusion..

Furthermore, additional calculations have been performed: influence of the different footprint shapes (goal of the paper attached and submitted). These analyses carried out understanding of the shape influence and the validity of the previous circular footprint approach (analytical and finite element, both axial symmetric)