Effect of Loading Type on Generated Stresses around a Circular Tunnel Lining in Sand

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Abstract:
The study is carried out to investigate the behavior of tunnel lining in sandy soil by evaluating the magnitudes of the generated stresses that are generally required to ensure the safety of tunnel construction. The testing program comprised different factors, i.e., sand depth, density with and without the effect of surface loading. The experimental work was accomplished through an instrumented (strain gauged) circular tunnel model. It was shown that the generated stresses, for different loading types, i, e., surcharge, circular or strip loading, decreased as the sand density increases for all regions (Crown, Shoulder & Spring-line) and they increase as the sand depth increases. The results are presented in the form of design charts.

Key- words: Tunnels, Lining, Stresses, Loading Type.

تاثير نوع الحمل على الأجهادات المتوولدة حول بطانة نفق دائري في الرمل

لخلاصة
أجري البحث لغرض دراسة تصرف بطانة نفق في التربة الرملية عن طريق تقيـيم مقـدار الأجهـادات المتولدة فيه والتي تتطلب تأمين عامل الأمان أثناء عملية الأنشاء. برنامج الفحوصـات تضـمن عوامـل مختلفة منها:- عمق الرمل، الكثافة مع وبدون تأثير الأحمال السطحية. الجزء العملي من البحث قد انجـز من خلال الاستعانة بانموذج نفق مختبري دائري مزود بخلايا تحسـس الاجهـال. النتـائج بينـت أن الأجهادات المتولدة نتيجة تغير نوع الحمل (الحمل المنتظم, الحمل الدائري, أو الحمل الشريطي) تقل كلما ازدادت كثافة الرمل ولجميع المناطق على محيط مقطع النفق وأن تلك الأجهادات تزداد مع زيادة عمـق الرمل. النتائج تم استعراضها على هيئة مخططات تصميمية.

Introduction:

When reviewing the previous literature on tunnels and buried structures two main techniques arise, the theoretical technique and the experimental technique. **Adachi et al (1985)** investigated the mechanical behavior of a shallow sandy ground tunnel through a thin flexible shotcrete lining in two kinds of laboratory model tests. A comparison is then made with the results of a finite element analysis. **Davies (1989)** conducted a fundamental study of two aspects of stress wave attenuation in the soil and the soil structure interaction resulting from the arrival of such wave. Eight pairs of strain gauges positioned around the middle segment of 100mm diameter brass cylinders were used to measure both hoop and bending strains. Soil stresses around the cylinder were measured using pressure cells.

Tunnel Model:

A circular cross-section tube (85mm diameter and 270mm length) made of 0.3mm thick plate was adopted as the tunnel model. The tunnel was placed in an iron container (4mm thick) with dimensions (500mm) in length, (300mm) in width and (600mm) in height. The front of the container consisted of a graphically striped glass (2x6mm thick) to facilitate observing the behavior of soil under load, refer to Fig. (1)

Soil used:

The soil was uniformly graded sand taken from typical construction work after separating undesirable particles. Soil properties, represented by both the

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Poisson's ratio and modulus of elasticity were recorded to be 0.3 and $37*10^6$ kPa respectively.

It is believed that many factors control the density of sand such as initial falling velocity, falling energy, quantity-discharged height of sand in the reservoir and other factors. Therefore a special device has been adopted in order to control sand density, i.e., rainier device, which was developed and used by **Hamamah (1994).** The rainier is basically a conical cylinder containing two internal perforated plates with holes of 6.5mm in diameter.

Three different densities were adopted in the research, i.e., (14.5, 15.3 and 16.2 kN/m^3) in order to assess the effect of sand density on the measured stresses. Table (1) summarizes the sand properties:

Instrumentation:

Electrical strain gauges 5mm length of wire type were mounted on the outer surface of the tunnel lining using half bridge circuit in order to measure the generated strains in the tunnel lining. Those strains were then calibrated and converted to stresses via a strain meter. The locations of these gauges were in the crown, the middle shoulder and the spring-line, see Fig. (1), as these points represent points of greatest positive and negative stresses, **Dessouki & Monforton (1986).**

Loading Types & Application:

Three different loading types were applied as follow:

1-Iron plates of dimensions (480*260*4) mm and 50N in weight were used as a surcharge.

2-Concrete cylinder 100mm in diameter placed on the soil surface above the centerline of the tunnel was used to represent the circular loading.

3-Wooden block of dimensions (270*50*30) mm was used to represent the strip loading.

Testing Program:

The effect of soil depth and density with and without surface loading were examined. The testing program was accomplished through the following experiments and preparations:

1- The sand was rained homogeneously from a height of 0.25m and stopped when the depth reached 100mm.

2-The tunnel model was then placed and readings of the strain gauges were recorded.

3-Sand raining commenced and then stopped at depths (Z)= 0, 85, 170, 255, 340 and 425mm measured from the highest point of the tunnel model, these depths represent 0, D, 2D, 3D, 4D and 5D respectively, (D= tunnel diameter). Strain readings were recorded for each depth.

The same steps were repeated for other raining heights (0.5m and 1.1m) to attain the specified densities.

Results & Discussions:

As an outcome of the large number of tests undertaken and the different factors covered in those tests, a number of design charts were obtained. These charts include the relevant factors affecting the design of tunnels. Design chart (1) is constructed to summarize the effect of sand depth and density for the basic problem (without external loads) in the crown, shoulder and springline regions. The required stress ratio at any point is obtained by drawing a line connecting any depth ratio (**Z/D**) and the specified sand density to intercept the adjacent vertical line, from which a horizontal line is drawn. Three types of stress ratio can be obtained, i.e., tangential (**$\sigma\theta/\gamma Z$**), longitudinal (**$\sigma l/\gamma Z$**) and shearing stress (**$\tau/ \gamma Z$**).

The effect of surface loading and sand density corresponding to a depth ratio of (Z/2D) are presented as Design chart (2), for surcharge loading case, Design chart (3), for circular loading case and Design chart (4), for strip loading case. The stress ratio at any point can be obtained by the same procedure mentioned above.

Conclusions:

The following conclusions could be drawn from these charts:

1- The value of tangential stresses is threefold the value of both longitudinal and shearing stresses.
2- The value of positive stresses in the crown region is greater than that of the negative stresses in the shoulder and spring-line by 50%.
3- The generated stress ratios increase as the sand depth increases until they reach their peak values at sand depth (Z=2D), after which they tend to decrease as depth increases.
4- An increase in sand density from 14.5 kN/m^3 to 16.25 kN/m^3 lead to a decrease in the generated stresses by about 77%.

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Table (1) Sand Properties

Sand density kN/m^3	Relative Density %	Classification	Raining Height m
14.5	20	Loose	0.25
15.3	49	Medium	0.50
16.2	78	Dense	1.10

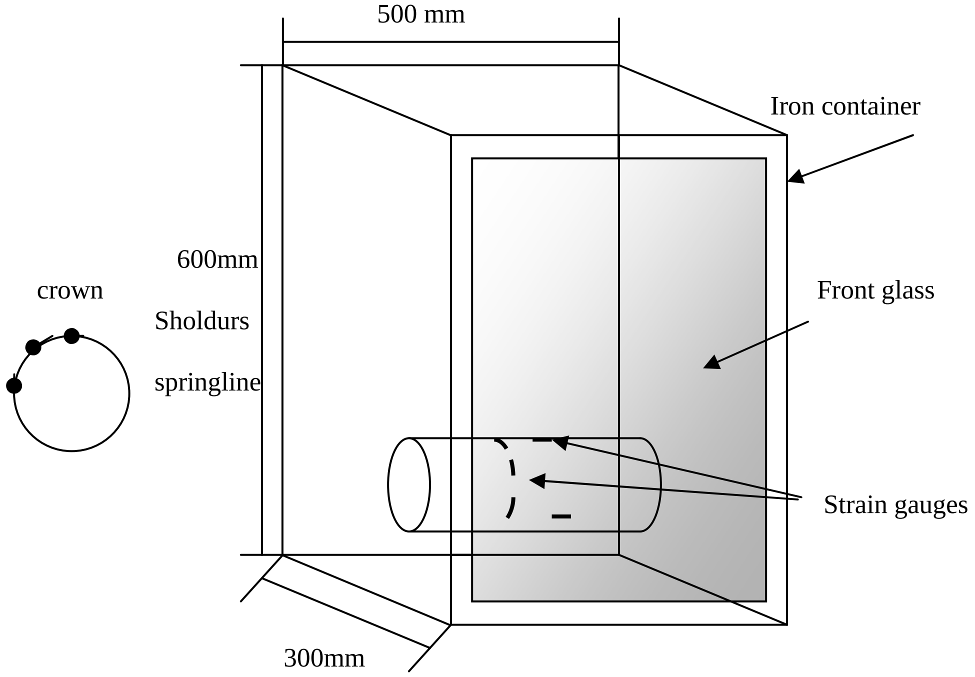
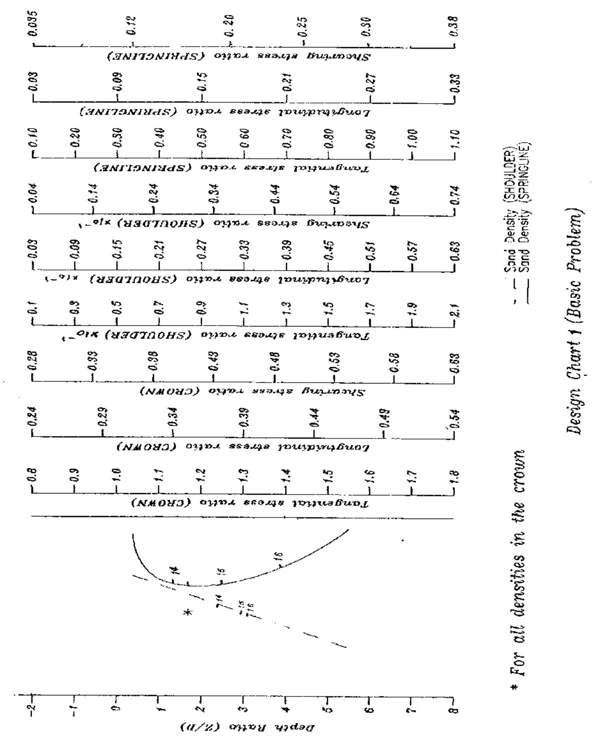
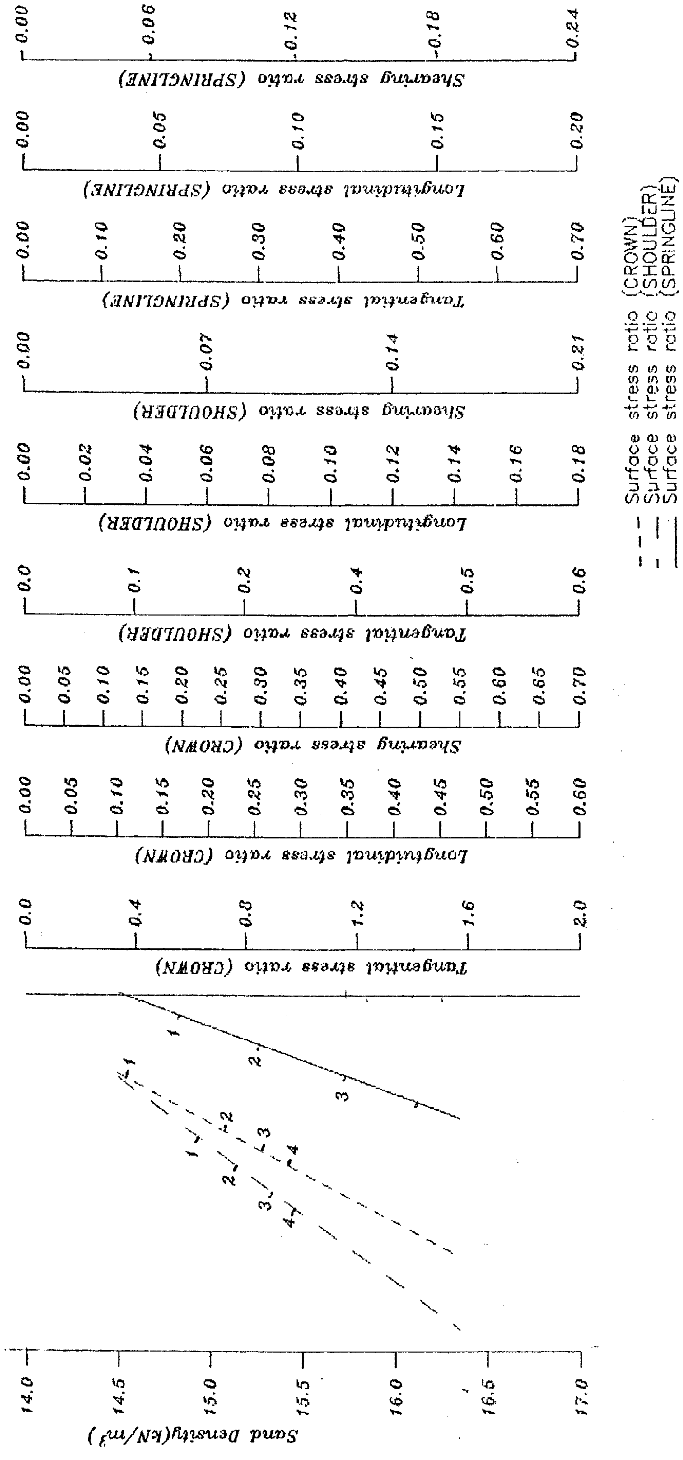
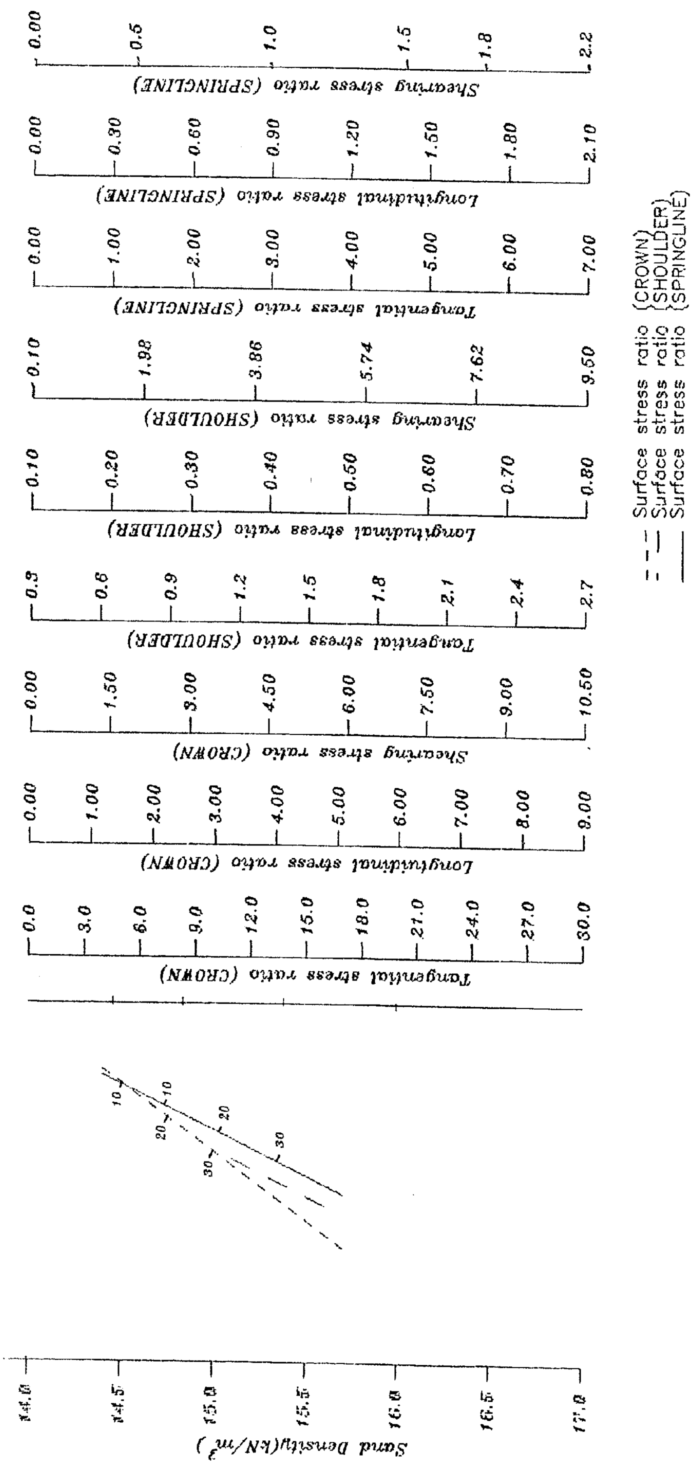


Fig.(1) Sketch of steel container showing tunnel model & location of strain gauges

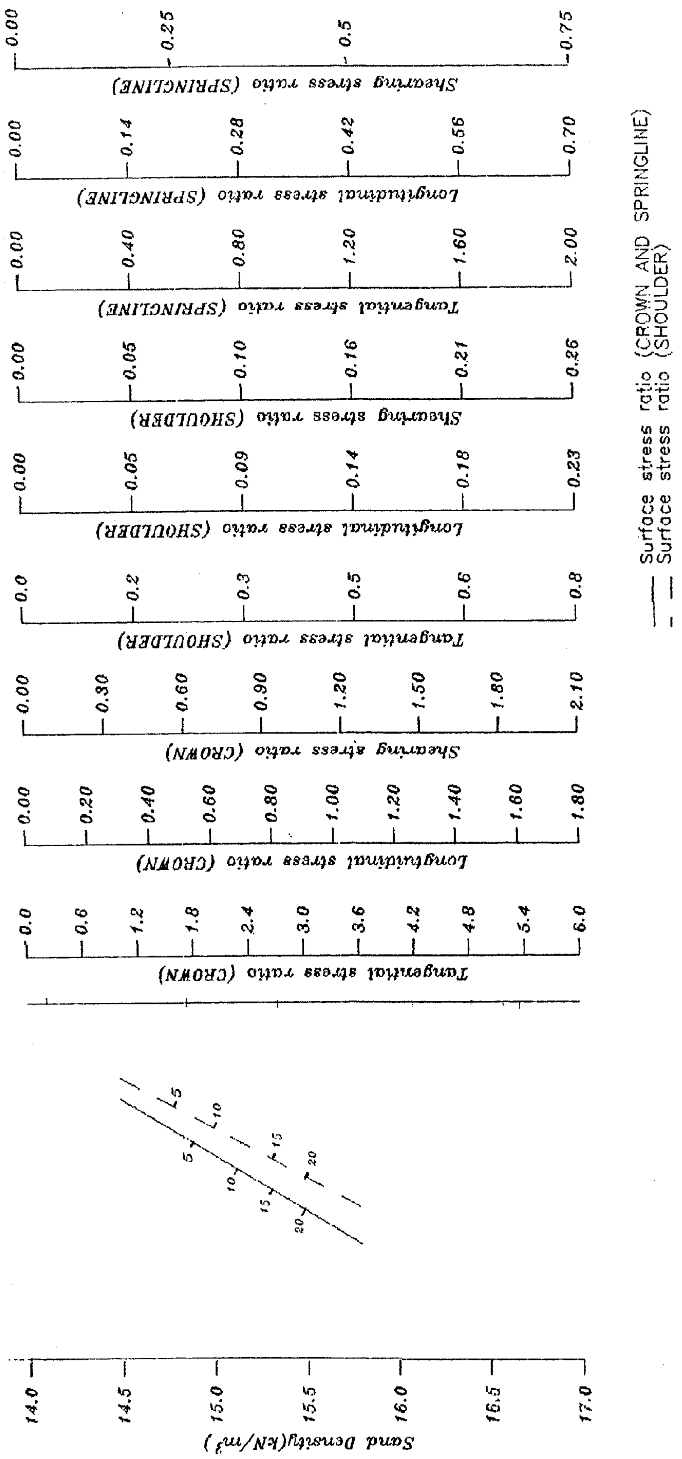




Design Chart 2 (Surcharge Z=2D)



Design Chart 3 (Circular Loading Z=2D)



Design Chart 4 (Strip Loading Z=2D)