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Studying the Behavior of Strengthened Four Shapes of RC Tunnels using Externally Bonded GFRP

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***Abstract*— Strengthening of reinforced concrete members by externally bonded fiber reinforced polymers (FRP) sheets or plates has been increasing in recent years due to the beneficial characteristics of being non-corrosive and generally resistant chemicals, high strength to weight ratio, and non-magnetic and non-conductivity of composite materials. The experimental results showed that better performance of the strengthened sections with GFRP could be achieved in terms of ultimate load, crack control, and stiffness. Application of GFRP to strengthen underground tunnels is one of the prime applications due to the severe environment, which the concrete is exposed. Repair work of underground tunnels such as "Ahmed Hamdi Tunnel under Suez Canal "or" El-Salam Tunnel under Suez Canal" is carried out mainly to strengthen the primary lining of the tunnel due to any defects or cracks.**

Experimental program contain four shapes of concrete tunnel "Circular section, Elliptical section, Egg-Shaped section and Horse shoie section" to investigate of the research work showed that the procedure described in this paper is stable, fast in convergence and effective for tunnels applications.

***Index Terms*— Lining, Tunnel, Strengthening, Circular and Experimental**

I. Introduction

External strengthening of tunnels by bonding steel plates has been applied in construction for over twenty five years. In many applications, the technique was found to be low cost, easy and distinguished by the fast application. However, the continuous development of new and improved materials to have better long-term durability, especially at the steel-adhesive interface, have led to the use of fiber reinforced polymers (FRP) as alternatives to the steel plates. Strengthening of concrete and reinforced concrete members by externally bonded fiber reinforced polymers sheets or plates has become increasingly common in recent years due to the beneficial characteristics of being non corrosive, generally resistant to chemicals, having a high strength-to-weight ratio, and of being non-magnetic and non-conductive. The Experimental results in the literature showed that strengthening concrete members with FRP could achieve better performance in terms of ultimate load, crack control and stiffness.

This paper presents an experimental work included four shapes of concrete tunnels "Circular section, Elliptical section, Egg-Shaped section and Horse shoie section".

a) Circular Tunnel Section, Fig.(1):

- This type of section offers greater resistance to external pressure.
- If ground is highly unstable, such as soft clay or sand, it is necessary to use circular section.
- For carrying water and sewerage circulation shape tunnels are used. Ex. Aqueduct.
- Circular tunnel are not prefer as traffic tunnel.

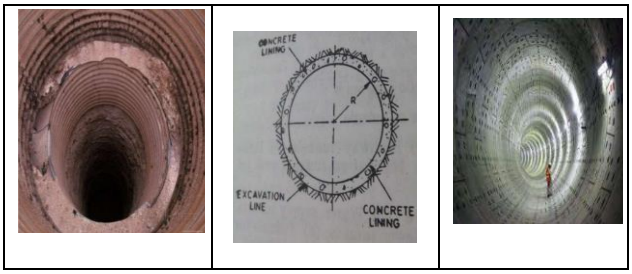

Fig.(1): Circular tunnel section

b) Elliptical Tunnel Section, Fig.(2):

- They are used in ground compare than rock.
- These tunnels serve as water sewage condition. They are difficult construct.
- They cannot be used as traffic tunnels because of their narrow base.

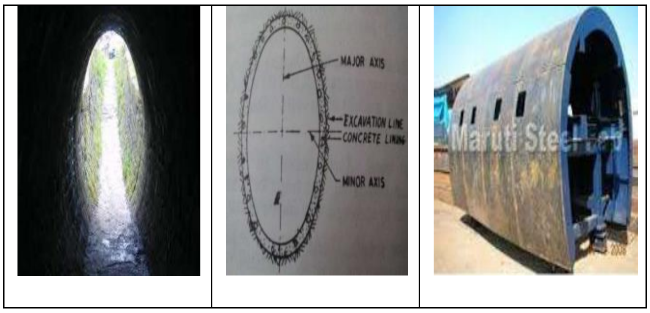

Fig.(2): Elliptical tunnel section

c) Egg-Shaped Tunnel Section, Fig.(3):

- These sections have narrow cross sections at bottom. They are best suited for carrying sewage.
- They maintain self-cleaning velocity of flow of sewage both in dry and rainy seasons.
- They are resist external as well as internal pressure due to their circular walls.
- These tunnels are difficult to construct.

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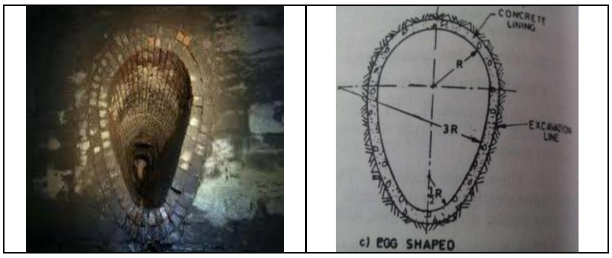


Fig.(3): Egg-Shaped Tunnel Section

d) Horse Shoie Tunnel Section, Fig.(4):

- This form consists of a semi-circular roof together with arched sides and a curved invert.
- They are most popular as traffic tunnels for road and railway routes.
- These tunnels are also difficult to construct.

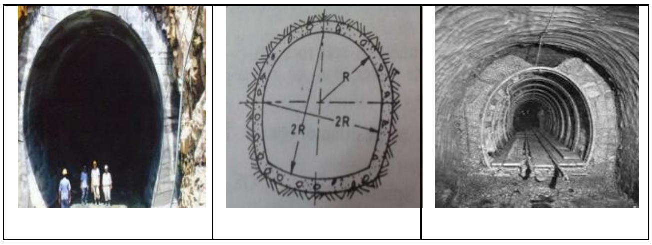


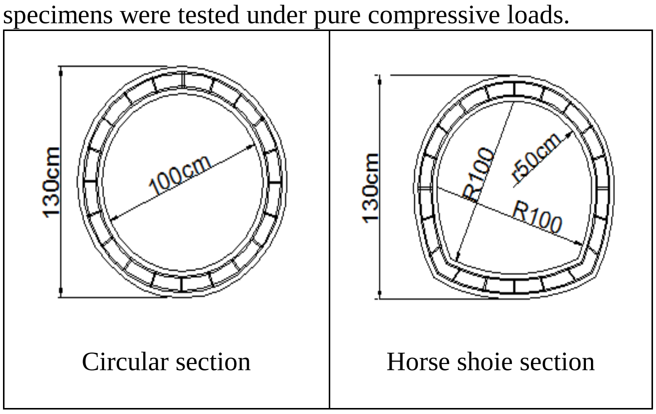
Fig.(4): Horse Shoie Tunnel Section

The experimental work included testing eight specimens, two from each type of tunnel, one as a control specimen and the other strengthened with double layers of glass fiber reinforced polymers (GFRP) bonded at the bottom surface of the specimens, concrete dimensions of the specimens was mentioned in the experimental program. The specimens were 150mm thick and 400mm wide. The results indicated a remarkable increase in the ultimate capacity combined with a reduction in the strains.

II. EXPERIMENTAL PROGRAM

A. Test Specimens

Eight tunnel segments were cast with the dimensions and reinforcement arrangement, as shown in Fig.(5). The tunnel segments had an inner diameter of one meter, thickness of 150mm and width of 400mm. Each specimen was reinforced by three bars of 10mm diameter at the bottom and three bars of 10mm diameter at the top. The specimens were also reinforced by stirrups of 5 bars 8mm diameter per meter. The specimens were tested under pure compressive loads.



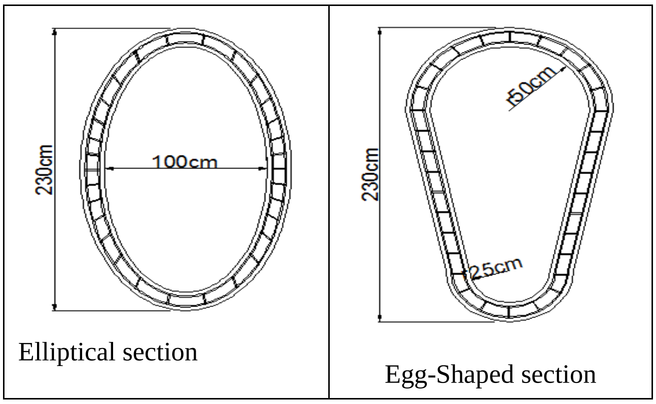


Fig.(5): Dimensions of the tested specimens

Four concrete specimens were tested as a control specimen without strengthening, while the other four specimens were strengthened with double layers of GFRP bonded at the bottom surface of the specimens as shown in Fig.(6), then tested.

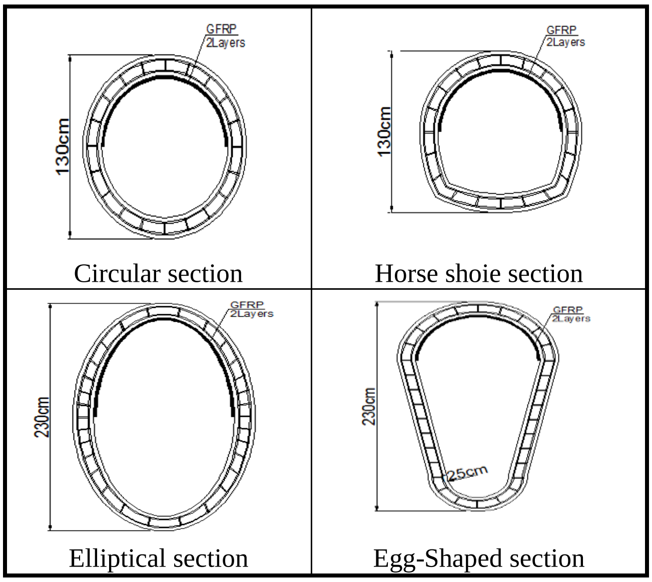


Fig.(6): Strengthened specimens

B. Material Properties

The concrete used has a nominal compressive strength of 30 MPa after 28 days. The steel used had a yield stress of 360 MPa for the bars more than 8mm diameter and 240 MPa for the 8mm diameter bars. The glass fiber sheets were 0.135 mm thick and 400mm wide. The ultimate strain and modules of elasticity of the sheets were 2.88% and 65 GPa, respectively, as reported by the manufacturer. The nominal tensile strength of the sheets was 1870 MPa.

C. Manufacture of Specimens

Before bonding the GFRP sheets, the concrete surface was prepared using a hand grinder to remove the cement paste on the surface and to expose the aggregates. They were then thoroughly wire brushed to remove all the loose particles, cleaned by vacuum, degreased by acetone and dried. Prior to bonding, 2mm thick metallic spacers were stuck on the RC specimen's surface to control the thickness of the adhesive. The epoxy adhesive was applied to the surfaces of the specimens and spread to develop a relatively uniform thickness. The GFRP sheets were then pressed against the prepared specimen surface using rubber roller. The entire bonding operation took less than half hour. For achieving full curing prior to testing, a minimum curing of 3 days was allowed after plating under standard conditions.

D.Testing Set-up

The strains in the longitudinal steel bars were measured by three instruments at top, bottom and side surface. As well as the external GFRP sheets were monitored using electrical strain gauges. The concrete strains along the central section were measured by using eight LVDTs with a nominal gauge length of 100mm. In addition, the central and the load point deflections of the specimens were measured through LVDTs.

E. Test Procedure

All of the test specimens were tested using two-point loading. For each test, the load was applied at a constant rate of approximately 0.5 KN/min, under load control up to failure of the specimen. The deflection and strains were measured at each load increment. The crack pattern and failure modes were determined for each test specimen.

III. EXPERIMENTAL RESULTS

Table (1) shows the ultimate carrying capacity for each test. For all the test specimens, a major flexure crack appeared at the mid-span of each specimen. In the first test, were un-strengthened specimens tested, the ultimate carrying load of the four shapes of tunnels "Circular section, Elliptical section, Egg-Shaped section and Horse shoie section" was 13ton, 17ton, 16ton and 10ton respectively. IN the second test, were the specimens strengthened with double layers of GFRP, the ultimate carrying load of the four shapes of tunnels "Circular section, Elliptical section, Egg-Shaped section and Horse shoie section" was 15ton, 19ton, 18ton and 13ton respectively.

Table (1): Test results

Specimen shape	No. of GFRP layers	Ultimate load (ton)	Tension reinforcement		Area of GFRP (mm2)	Failure modes
			Type	As/Ac		
Circular section	---------	13	D10*6	0.6%	--------	FTF
	2	15	D10*6	0.6%		SF
Elliptical section	---------	17	D10*6	0.6%	--------	FTF
	2	19	D10*6	0.6%		SF
Egg-Shaped section	---------	16	D10*6	0.6%	--------	FTF
	2	18	D10*6	0.6%		SF
Horse shoie section	---------	10	D10*6	0.6%	--------	FTF
	2	13	D10*6	0.6%		SF

Note: FTF "Flexure tension failure", SF "Shear failure"

The strengthened specimen with GFRP sheets failed due to occurrence of a shear crack close to the applied concentrated load. The results clearly indicate that various shape of tunnels give various ultimate carrying capacity in strengthened and un-strengthened specimens, this mainly due to the different shapes of specimens. The increase in the ultimate load due to strengthened with two layers of GFRP about 20% in the four shapes of tunnels.

The load deflection curves of all the test specimens are shown in Fig.(7) to (10).The stiffness of the specimen, which is indicated by the slope of the load-deflection curves, increased by the increase of the inner dimension.

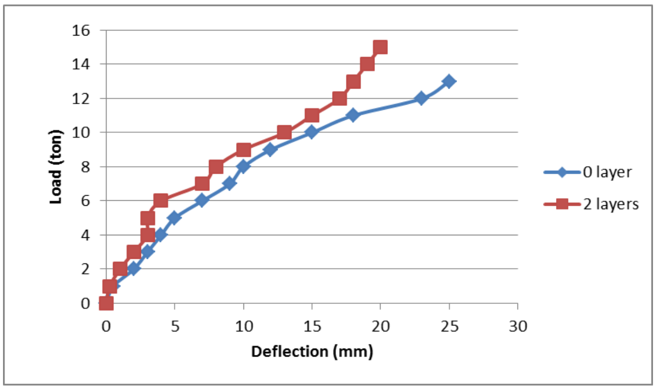


Fig.(7): Load-deflection curves for circular section

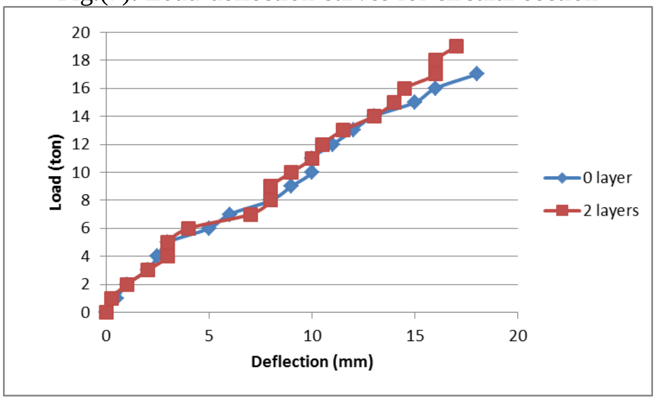


Fig.(8): Load-deflection curves for elliptical section

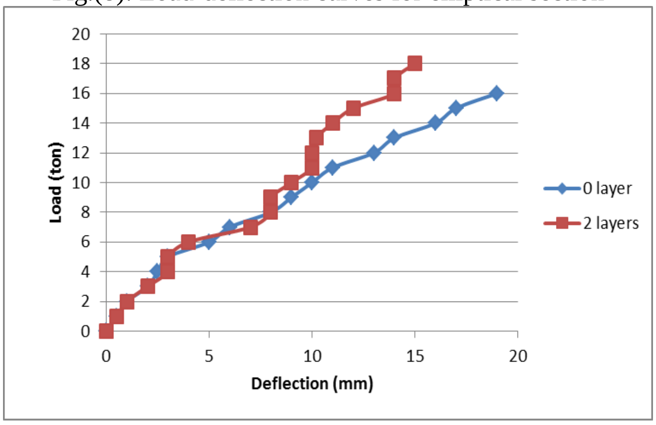


Fig.(9): Load-deflection curves for egg-shaped section

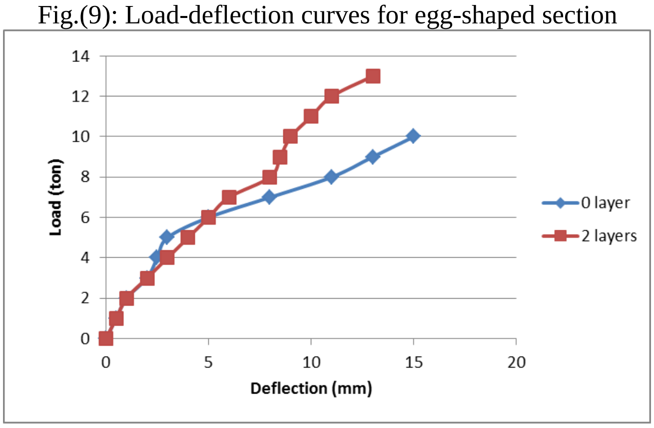


Fig.(10): Load-deflection curves for horse shoie section

IV. CONCLUSIONS

This paper presents four shapes of concrete tunnels strengthened with double layers of GFRP sheets. The following conclusions are drawn:

1- Strengthening concrete tunnels with GFRP at the bottom surface is effective in increasing the ultimate failure load.

2- Elliptical section of tunnels is more effective than the other shapes.

3- Strengthening concrete tunnels with double layer of GFRP increased the ultimate load for about 20% in the four shapes.

4- The stiffness of the specimen, which is indicated by the slope of the load-deflection curves, increased by the increase of the inner dimension.

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