A Study on Deflection of GRP

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Abstract:

GRP have been widely used in both potable water and waste water transmission. A large part of GRP's ability to support loads and/or pressures may be derived from the passive pressure of the enveloping fill material. So, failure of GRP usually results from pipe deflection rather than rapture of the pipe wall.

It is the objective of this paper to shed more light on the stability of GRP. Finite element method has been used to investigate the GRP deflection under both hydraulic and bedding loading conditions.

It has been found that the pipe deflection depends, to a large extent, upon the pipe stiffness, the bedding and filling materials properties.

Introduction:

Nowadays, Glass Reinforced Pipes (GRP*)* have been widely used in most of the fluid transportation applications. Potable water distribution and waste water collection system is one of the most common areas in which the *GRP* have been used. This is due to the fact that *GRP* pipes have many advantages e.g. high chemical resistivity, light weight, variety of produced diameters, and different rigidities allow them to resist internal and external loads and stresses. Fig. (1) shows the distribution of external forces around the pipe (6) ..

However, *GRP* as all flexible pipes, usually fail by deflection rather than by rapture of the pipe wall. Deflection of *GRP*, as shown in fig. (2) under vertical earth loads results in less vertical diameter and greater horizontal diameter (3 and 6). Such deflection and/or deformation of *GRP* may lead to system leakage, loss of the hydraulic gradient. The leakage, in turn will affect the pipe supporting system due to the fact that the water will change the water contents in the surrounding soil and subsequently will affect its stability.

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GRP has relatively little inherent strength, and a large part of its ability to support vertical load must be derived from the passive pressure induced as the sides move outward against the enveloping fill material. The passive resistance of the enveloping fill material against the pipe should keep the actual deflection of the pipe considerably below the amount the pipe would deflect if acted upon the vertical earth loads alone (4, 5, & 7) Some precautions should be considered in the bedding and filling around the *GRP* as the safe behavior of *GRP* from leakage point of view depends to a very large extent on the bedding under the pipe and the filling around it .

It is apparent from the above considerations that any attempt to analyze the behavior of the *GRP* must take into account the bedding and/or material under and around the sides as an integral part of the pipes, since such a large proportion of the total supporting strength is attributable to this material. Since the structural and hydraulic behavior of *GRP* depends upon the supporting strength of the pipes (2), it is the objective of this paper to shed more light on the deformation behavior of the *GRP* under different bedding conditions and pipe rigidities .

Material & Method:

The *GRP* samples used in this study were obtained from a 700 mm diameter pipe manufactured by the filament winding method. The average wall thickness of the pipe was 83 mm. The mechanical properties of those samples have been tested in the central department for scientifical analysis and tests in the National Research Center at Cairo, Egypt. The tests have been carried out at two different temperatures, namely 20°C (room temperature) and 50°C. The different temperatures were decided to evaluate the effect of the climate conditions in the Egyptian hot summer on the *GRP* pipes performance. The tensile strength and bending strength of the pipe material were determined at the two temperatures (20°C and 50°C) in two directions, namely the longitudinal direction (LC) and the perpendicular or circumferential direction (CM). The results of the tests are summarized in tables (1-a) and (1-b). Also, the samples thickness and dimension were also measured before and after heating. No changes have been recorded in the dimension of these samples due to the heating of the samples @ 50°C for 24 hrs.

The rigidity (PS) of the investigated *GRP* samples, and consequently the modulus of elasticity (E), were determined. Table (2) shows the values of both PS and E of the tested samples. Furthermore, the pipe deflection has been analyzed under different backfill compaction conditions. The different modulus of elasticities for the bedding materials are shown in table (3) and the bedding's different layers are shown in fig (3).

Table (1-a) Results of Tensile Strength (T) Tests in the longitudinal Direction (CL)

Sample No.	Tensile strength (T) in CL direction (kg/cm^2) (@ 20°C (room temp.)	@ 50°C*
1	623	614
2	614	609
3	570	597
4	550	594
5	519	499
Average	575	580

* *Samples were heated for 24 hrs.*

Table (1-b) Results of Tensile strength (T)Tests in the circumferential direction

Sample No.	***Tensile strength* (T) *in the CM direction* (kg/cm^2)**	
	20°C (@ room temp.)	**@ 50°C**
1	2326	2355
2	2155	2167
3	1949	2102
4	1829	1790
5	1369	1361
Average	1925	1955

Table (2) values of PS and E of the tested samples

Sample No.	PS N/m^2	E* N/mm^2
1	206602	31360
2	193939	31309
3	168706	30690
4	181997	34074
5	173361	35655
Average	184921	32617

$$E = 1.788(PS)\left(\frac{r}{t}\right)^3\left(1 + \frac{\Delta y}{2d}\right)^3$$

Where

r = The pipe radius
t = The pipe wall thickness
d = The pipe diameter
Δy =Vertical deflection

Also, the deflection lag factor "D_t", was included in the deflection analysis. The deflection lag factor cannot be less than unity and has been observed to range upward toward a value of 2.0. It appears to depend upon the quality of the soil at the sides of the pipe. A well-graded dense soil will permit very little, if any, residual deflection, and the lag factor can safely be ignored; while a loosely placed soil may induce a relatively large deflection lag. Except in the case of very high quality, well-compacted backfill soil, a deflection lag factor of about 1.25 is recommended for design purposes (7). For best results, the backfill soil should be compacted for a width of one or two pipe diameters on each side of the pipe. The formula used for computing the deflection of a flexible pipe is:

$$\Delta_x = D_t\,(K w_e r^3 / EI + 0.061\,E'r^3)$$

Where

Δ_x = horizontal deflection of pipe in mm (in) (my be considered the same as the vertical deflection),

D_t = deflection lag factor,

K = a bedding constant, its value depends on the bedding angle; $\propto$ in Gig. 27 (1), w_e = vertical load per unit length of the pipe in N/m (Ib/in.)

r = mean radius of the pipe in mm (in.)

E = modulus of elasticity of the pipe material in kPa (Ib/in.^{2})

I = moment of inertia per unit length of cross section of the pipe wall in mm^4/mm (in.^{4}/in.)

E' = er = modulus of soil reaction in kPa (1b/in.^{2})

e = modulus of passive resistance of the enveloping soil in kPa/mm (1b/in.^{2} per in).

It should be mentioned here that the deflection of the flexible pipes should not exceed the value of 5 % of the normal pipe diameter (1).

Modeling:

Deflection of buried *GRP* results from external and/or internal loads. The external loads may include the vertical and the horizontal soil pressure which can be supercomposed with live loads from cars, trucks ..etc. Those loads are governed by several factors such as native soil properties, trench width, backfill material and its properties, live loads. The internal loads are from the hydraulic parameters and are governed by fluid flow rate, maximum working pressure (including surge and negative pressures), operating temperature, and characteristics of the fluid.

Table (3) Values of soil modulus of elasticity (E) in kg/cm^2 (0.1 N/mm^2) for the different backfill compaction conditions.

Case No.	E1	E2	E3	E pipe
BD1	100	150	200	326000
BD2	100	150	200	210000
BD3	100	150	200	240000
BD4	70	200	200	326000
BD5	100	200	200	326000
BD6	150	200	200	326000

In the present model, an external live pressure of 2.5 t/m^2 and a negative pressure of 1 t/m^2/m' acting on the circumference have been used in the analysis. The models, then, were analyzed by Finite Element Method (F.E.M.) and the mesh is shown in fig. (4,a & b). Fig.(4-b) shows the pipe wall nodes. Six different bedding conditions table (3), have been investigated and the deflection analysis has been carried out for each case.

Results and discussions:

In this study the effects of bedding and filling conditions and pipe stiffness on *GRP* deformation have been investigated. The results of this investigation will be presented and discussed in the following sections.

Effect of Pipe Stiffness:

An analytical model for the flexible pipe *(GRP)* has been introduced and then analyzed using F.E.M. *GRP* of different stiffness values were investigated under an external load using the model at various depths. The results of this investigations as shown in Fig. (5), yielded two trends:

a) Pipe deflection decreases as pipes rigidity increases, for the same laying depth.

B) For the same pipe rigidity, the deflection increases as the laying depth increases.

Regarding the laying depth, the pipe deflection is directly proportional to the laying depth while it is inversely proportional to the pipes rigidity. This means that the higher the pipe stiffness the lower the deflection as the pipe rigidity indicates its ability to resist external soil and traffic loads.

Effect of Bedding Properties:

Current pipes design practice uses backfill material of high modulus of elasticity with lower modulus pipe. Table (4) shows the various modulus of elasticity, E, for the different Types of backfill materials.

Table (4) Backfill type and its modulus of elasticity, E, N/mm^2 (after HOBAS, 1995)

Backfill Material Description	Compaction	E N/mm^2.
Crushed rock	Dumped	20
Pea gravel	Slight	15
Gravel, max. 5% fines less than 0.06 mm.	97%	10
	92%	7
Gravel, max. 15% fines less than 0.06 mm	95%	7
	95%	4
Sand, max. 5% fines less than 0.06 mm.	95%	3
Sand, max. 15% fines less than 0.06 mm.	90%	2
Mixed soils, max. 40% fines	80%	1
fines > 40%		

The distribution of forces acting around the pipe, in the bedding zone, is shown in fig. (1). The magnitude of these forces depends on both the backfill material's density and its modulus of elasticity E. It should be mentioned here that the properties of the bedding material (ς and E) are among the main factors that control the pipe deformation.

To demonstrate the effect of the backfill properties in the deformation of the pipe under investigation, four cases for bedding material type, (BD1, BD4, BD5, and BD8) were investigated. Fig.(6) shows the effect of backfill properties and depth upon the pipe compressibility.

From the results shown in Fig. (6) it is clear that the modulus of elasticity of the bedding and filling material affects the compressibility of the flexible pipe. For the same laying depth the higher the modulus of elasticity, the lower the pipe compressibility as shown for curves of BD_1 ($E_2 = 150$ N/mm^2) and BD_5 ($E_2 = 200$ N/mm^2). The same trend has been drawn where the modulus of elasticity (E_1) has been changed from 70 to 150 .

The Effect of G-Bolt:

Two aspects of G-Bolt-pipe interaction will be discussed, namely; G-Bolt material and G-Bolt length. The installation of pipes with different G-bolt is a common practice. It is expected that deformation of them will be different, however, this will not affect the system as long as the separation between them had not occurred. If a complete separation of G-Bolt from pipe took place, the fluid leakage will occur and loss of the hydraulic gradient, and the changing of the bedding properties will take place. The G-Bolt critical length (LC) is the minimum required length at which the pipe wall G-Bolt separation will not occur.

The separation of the G-bolt-pipe wall may be attributed to: 1) the difference in material properties between the two materials, e.g. the installation of the *GRP* using cast iron G-bolt; resulting in different deformation, and 2) the different loading conditions when a hammer action take place on the pipe wall without affecting the G-bolt. This will not happen if there is enough length of the G-bolt covering the connection area of the pipes. However, increasing the length (LC) of the G-bolt is not an economical solution .

To investigate the effect of G-bolt length on *GRP* behavior, the same model mentioned before in this paper has been used as well as F.E.M. Different cast iron G-bolt lengths were chosen for this study. The G-bolt lengths, of 10, 15, 20, 30, and 40 cm were tested for pipe used in the present work.. The modulus of elasticity for the cast iron G-bolt was 2100 t/cm^2.

The obtained results showed that under the same external loading and bedding conditions, the separation between them can take place if the length of the G-bolt is less than 20 cm. This is in agreement with the min. length of 19 cm showed in HOBAS. However a more thorough investigation should be applied for the different pipe diameters and properties, which are available in the market, as well as the internal and external loading conditions of the specified pipes .

Conclusions and Recommendations:

Based on the analyses conducted in this paper, the following conclusions and recommendations may be drawn:

☞ (1) Design of *GRP* bedding is an indispensable part of the most economical and safe design of *GRP* pressure lines.

☞ (2) Proper *GRP's* rigidity, should be considered to minimize the pipe deflection for the same laying depth.

☞ (3) The higher the modulus of elasticity of the fill (E), the lower the pipe deflection for the same laying depth (BD4, 5, 6).

☞ (4) The higher the modulus of elasticity of the surrounding material (E2), the lower the pipe deflection.

☞ (5) Separation of the G-bolt-pipe wall should be avoided using:
  a- G-bolt made of the same *GRP* material, and
  b- Suitable length of the G-bolt covering the connection area of the Pipes.

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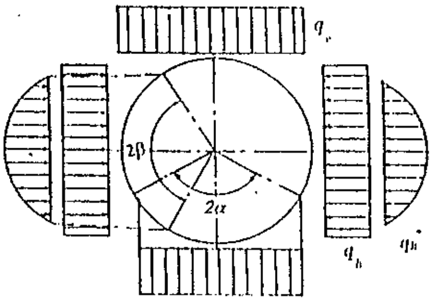
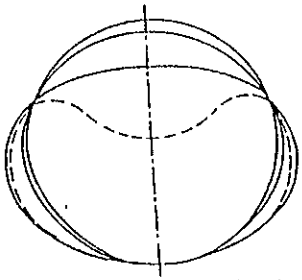


Fig. (1) Distribution of External Forces acting on Pipe *(after 6)*



Stages of deflection of flexible-pipe culvert

Fig. (2) Flexible pipe deflection at different loading conditions *(after 3)*

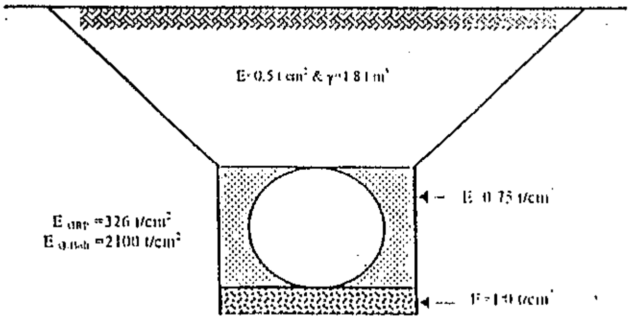
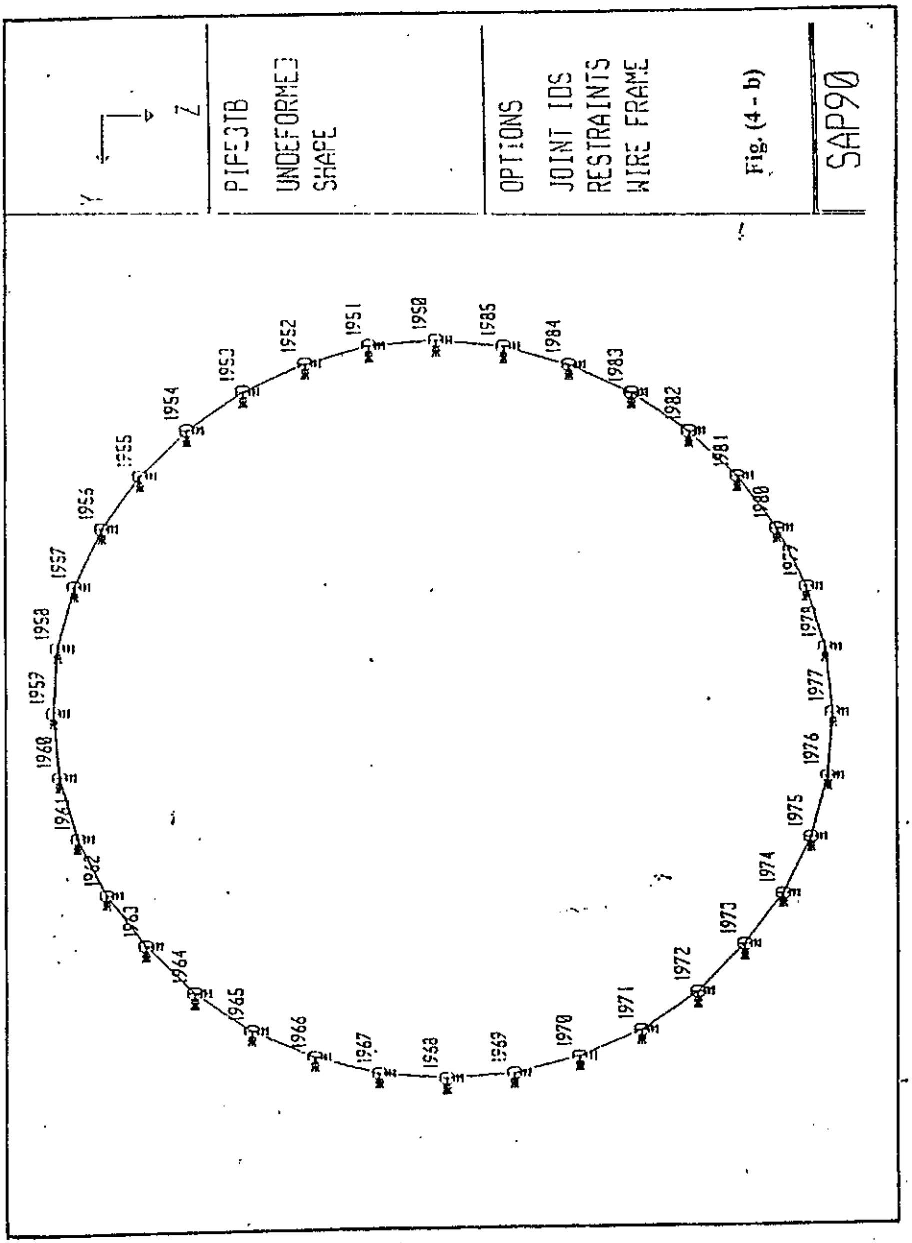


Fig. (3) Bedding properties used in analytical model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OPTIONS
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RESTRAINTS
WIRE FRAME
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Fig. (4 - b)

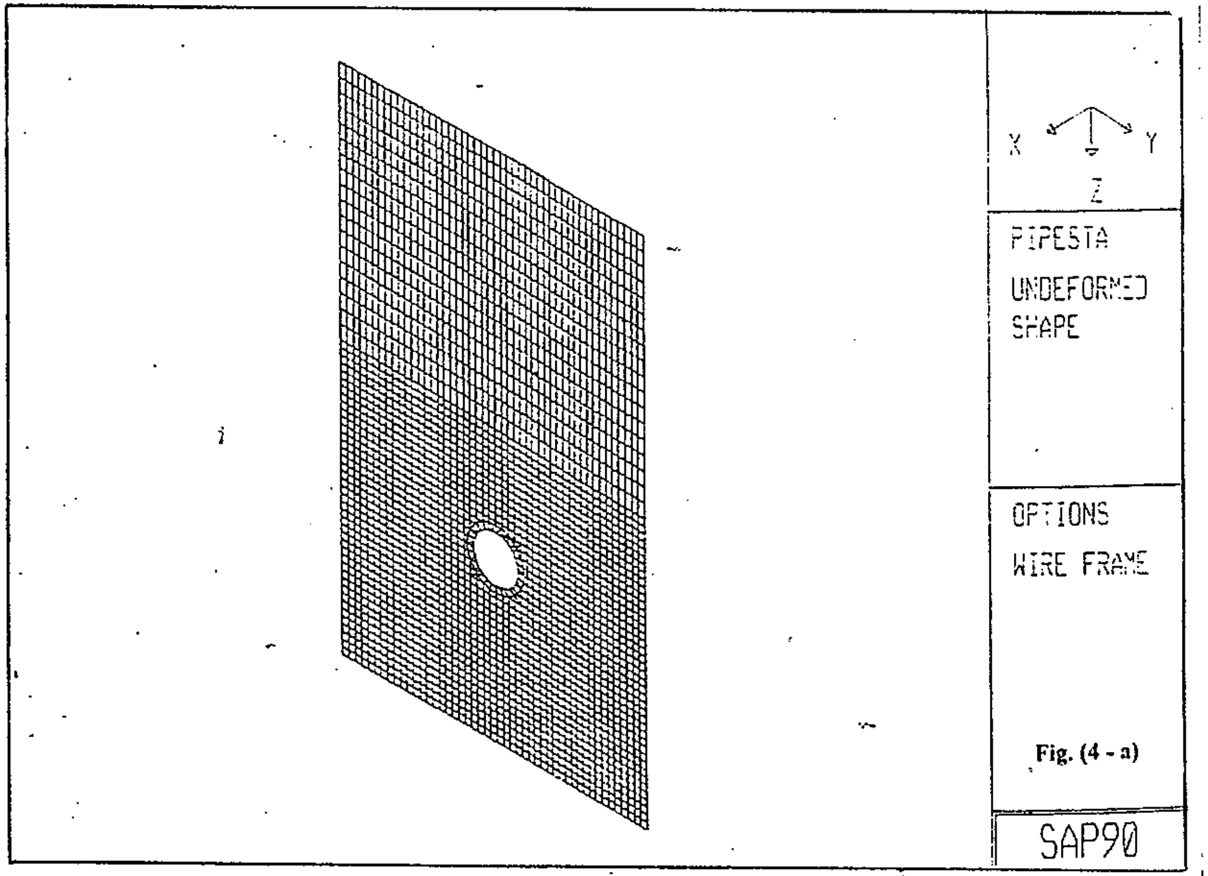

Fig. (4 - a)

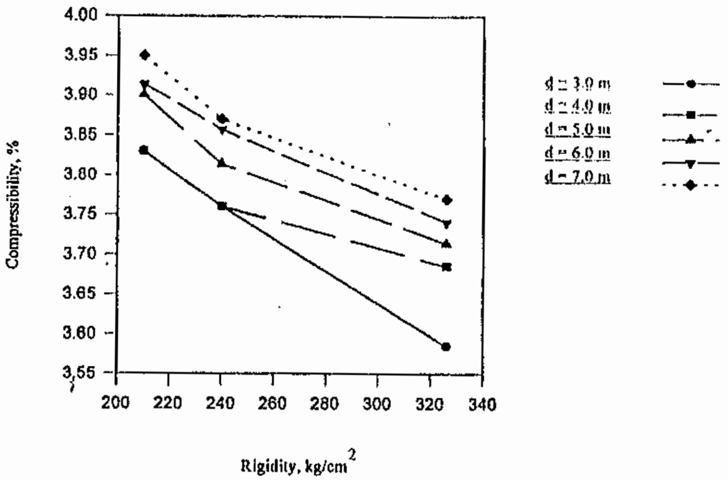

Fig (5) Relationship between pipe rigidity , depth, and compressibility

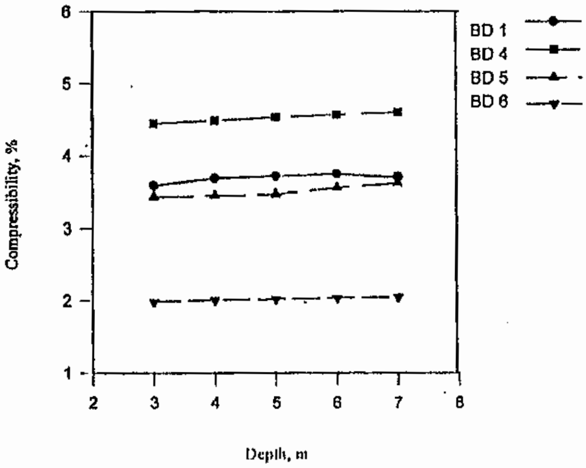

Fig. (6) Relationship between bedding condition, depth, & pipe compressibility.

دراسة عن ترخيم مواسير الزجاج المسلح

د٠ ضياء صلاح الدين المنيرى

تستخدم مواسير الزجاج المسلح على نطاق متسع فى مجالى مياه الشرب والصرف الصحى ،وتستمد هذه المواسير جزءاً كبيراً من قدرتها على تحمل أو نقل الأحمال والضغوط المعرضة لها من الضغط السلبى لمادة الردم المحيطة بها٠ لذلك فعادة ً ماينتج انهيار هذه المواسير من ترخيمها أو انبعاجها لا انهيار جدار المواسير نفسها ٠

يهدف هذا البحث لإلقاء مزيداً من الضوء على ثبات واتزان مواسير الزجاج المسلحة ،واستخدمت طريقة العناصر المحدودة (Finite Element Method) لدراسة ترخيم مواسير الزجاج المسلح تحت تأثير كلاً من الظروف الهيدروليكية وظروف التأسيس والردم حول المواسير ولقد تمت دراسة ترخيم مواسير الزجاج المسلح وعلاقتها بجساءه (Stiffness) هذه المواسير وكذا تأثير مادة التأسيس والردم المستخدمه معها على ترخيم هذه المواسير٠