

# Exploring the structural behavior of recycled aggregates concrete pipe under dynamic loads through experimental and numerical investigation

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## ABSTRACT

The most used material in construction is concrete. This study aimed to investigate the impact of recycled aggregate on compressive and tensile strength in concrete. To address the issue of accumulating tons of recycled aggregates, a new method was developed using chemical additive fractions to convert these aggregates into valuable products. The overconsumption of materials is a significant problem that leads to route overflow, pollution, and road fragmentation. The mechanical properties of corroded concrete pipes were also examined through a series of tests and the development of an ABAQUS-based 3D finite element model. It was discovered that the inside of the pipe wall was more vulnerable to damage than the outside, with corroded areas experiencing large stresses and strains. As corrosion depth increased, so did maximum principal stress and hoop strain in the affected region. Fear increased rapidly at first (0-10°), then decreased rapidly (10-45°), before gradually decreasing with increasing erosion latitude (45-180°). Additionally, both circumferential strain and maximum principal stress increased rapidly with greater depth of coverage or increasing moving loads.

**Keywords:** Recycled aggregates, compressive and tensile strength, deferent loads.

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## 1. Introduction

Due to its favorable effects on both the environment and the economy, recycled aggregates are being used more frequently in the creation of concrete. However, it is still unclear how recycled aggregate concrete (RAC) pipes will behave structurally when subjected to moving loads. The structural behavior of RAC pipes under moving loads was therefore investigated through an experimental and numerical study. In Iraq, it is reported in the annual (2011) environmental census statistics of the Ministry of Planning's Central Statistics Office. The proportion of total waste is 48,085 tons per day, with construction waste generated accounting for 39.7% of the total waste, with the largest amount of debris in Baghdad accounting for 20% of all Iraqi debris. These statistics can be confirmed in a study [4]. In recent decades, government agencies and the construction industry have recognized the clear need to recycle old building materials due to rising waste storage costs and depletion of natural resources. Among various construction wastes, old concrete has emerged as a promising source of recycled aggregate that can meet moderate performance requirements for civil engineering applications. While previous research has primarily focused on treating recycled concrete and examining its properties, there is a lack of studies on the performance of structural members made from recycled concrete (RAC), such as beams, columns, joints, and frames. [5-7]

## 2. Literature

### 2.1 Concrete pipe

Concrete pipes are the ultimate option for long-lasting pipe systems. Engineers, transportation departments, and contractors nationwide trust precast rigid concrete pipes (RCP) to be the most durable choice, with a lifespan of more than a century. Recycling is the process of transforming waste into new materials and objects. Recycling is one of the most important parts of the tri series he called 3R. It is one of the most important environmental symbols and terms in the field of sustainable development. This involves many processes (reduction, recycling, reuse) [8]

*Strength:* Precast concrete pipes are the strongest drainage pipes on the market and are manufactured according to ASTM and AASHTO standards. Reinforced concrete pipes are composite structures, specially designed to take advantage of the best properties of concrete and rebar. Concrete is designed for compressive forces and reinforced for tensile forces.

*Resilience:* A strong and durable concrete pipe is defined by Webster's dictionary as 'withstanding long periods of time without significant deterioration'. For concrete pipes, durability refers to the expected life and durability of the material.

### 2.2 Recycling of concrete waste

Recycling is the process of repurposing waste materials into new materials and products [20]. In the three-series known as 3R, recycling is one of the most crucial elements. It is one of the most important environmental symbols and terms known in sustainable development. It includes a range of processes (reduction, recycling, and reuse).

*Reduction:* It is intended to reduce the materials used and thus reduce the waste generated using less raw materials or by using raw materials that produce less waste or by reducing the materials used in packaging processes such as plastic and paper.

*Recycling:* The process of using some residues as raw materials for the production of new materials that differ in their characteristics from the materials used for their production, and include many materials such as metals, paper, plastic and electronic devices.

*Reuse:* Materials reused in construction include no change in their physical and chemical properties but can be altered as needed [9].

In our study we are recycling concrete waste which is a part of construction waste which is a group of redundant materials that are not useful for use and are usually collected from building materials.

The concrete waste includes the debris resulting from the construction and demolition processes of the various facilities, as it results from the restoration of existing facilities, the demolition of the old ones, or the construction of new buildings, Mortars of different sizes. Damaged concrete is recycled into aggregate instead of natural debris and it must pass through two main steps: breaking and crushing of concrete blocks, Isolation, and classification of construction waste [10-24].

### 2.3 Improving the RCA concrete

From the literature, it is known that the use of recycled aggregates will reduce the strength of the concrete due to the weak edges of the recycled aggregates and the ability to absorb a large quantity of water. In this project, two admixtures will be used to improve the mechanical properties of the recycled concrete aggregate. SBR (Styrene- Butadiene – Rubber) and Micro polypropylene fibers (PPF) have been mixed with different proportions to improve the compressive and tensile strengths of the concrete.

SBR (Styrene- Butadiene – Rubber): Micro polypropylene fibers (PPF):

## 3. Significance of this project

The objective of this project is to enhance the mechanical properties of concrete and concrete pipes made using recycled aggregates as a partial or complete substitute for natural aggregates. As mentioned before, the use of recycled aggregate has many advantages, and the additives used in this project, SBR (Styrene - Butadiene -

Rubber) and Polypropylene Microfiber (PPF), can be made from recycled materials which are very beneficial to the environment.

### 3.1 Concrete mixes

The mixtures used were divided into 6 groups as shown below.

Table 1. proportions of materials used in mixtures<sup>2</sup>.

Mix	Cement kg	Sand kg	Gravel kg	RA kg	SBR %	PPF%	w/c ratio
Mix1	6	10.5	16	0	0	0	3
Mix2	6	10.5	0	16	0	0	3
Mix3	6	10.5	0	16	1	0	3
Mix4	6	10.5	0	16	2	0	3
Mix5	6	10.5	0	16	0	1	3
Mix6	6	10.5	0	16	0	2	3

### 3.2 Concrete pipe test results

1. Compressive Strength test: The compressive strength was determined according to ASTM C39/C39M-18 Standard Test Method for Compressive Strength of Cylinders concrete specimens [3].
2. Test for Splitting Tensile Strength: In accordance with ASTM C 496/C 496M - 04 [2], a test for concrete's splitting tensile strength was performed.
3. Concrete pipe test: The concrete pipe will be tested by applying transverse loading in way like the tensile splitting test as shown in the figure below [3].

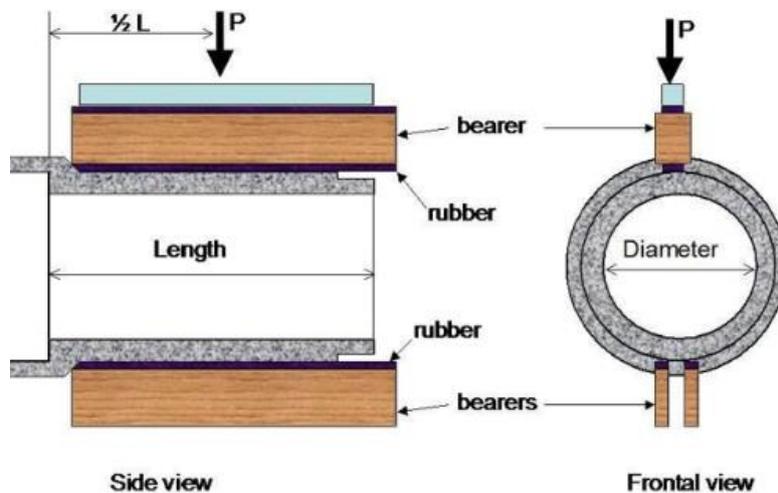


Figure 1. Pipe testing



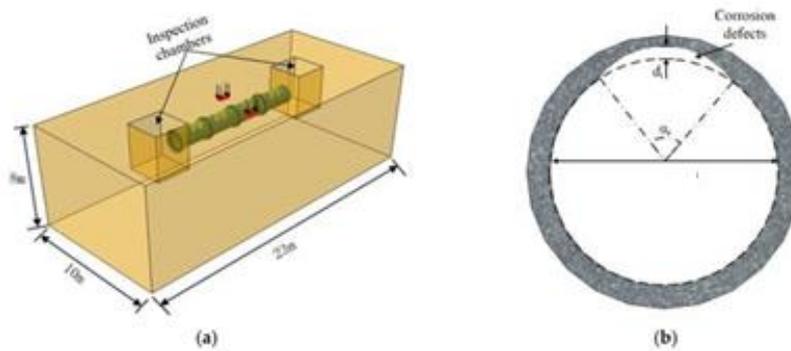
Figure 2. compressivestrength, splitting tensilestrength

Table 2. compressive strength, Splitting tensile strength, and concrete pipe test<sup>4</sup>.

Mix	Average compressive strength (MPa)	Average Splitting tensile strength (MPa)	Concrete pipe test (MPa)
Mix 1	30.3	3.1	34.8
Mix 2	21.6	1.9	21.35
Mix 3	23.7	2.4	27
Mix 4	26.1	2.75	30.9
Mix 5	21.9	2.78	31.2
Mix 6	22.5	3.2	35.9

### 3.3 Model description

ABAQUS is a high level widespread limited component framework and one of the most remarkable limited component programming for investigating complex strong mechanics and underlying mechanics frameworks. Consequently, a three-layered model of a covered eroded gasketed ringer nozzle supporting substantial seepage pipeline with two review chambers was created utilizing ABAQUS limited component programming (Figure 3a). The model measured 23, 10, and 8 meters in length, width, and height, respectively. A sand bedding with thickness of 0.15 m was set at 120° underneath the pipeline. Each end of the pipe had a chamber for inspection. The inspection chambers measured 2.5 m in length, 2.5 m in width, and 3.0 m in height, respectively. The full-scale test's pipe size is consistent with the numerical simulation models. The corrosion that decreased the wall's thickness was mimicked by excavating the pipe wall at the crown (Figure 3b).  $d_i$  is the consumption profundity and  $\alpha_i$  is the erosion width, communicated as the cross-sectional point at the spring line subtended by the bend of the consumption harm (in degrees).

Figure 3. (a) Modelling (b) Pipe <sup>8</sup>.

It is basic for precise numerical recreation to control component quality and to pick a suitable component type. Hypermesh 13.0 was utilized to mesh the model due to the pipeline's bell-and-spigot joints and the intricate mesh. Following completion of the meshing process, the elements were exported into Abaqus for calculations. The minimum and maximum mesh sizes of the model were 0.02 m and 0.1 m, respectively, taking into account both the computer's operational efficiency and sensitivity analysis results of the elements. Close pipeline soil components were thickly coincided, and more far off components were scantily fit. Shear locking was avoided by employing C3D8R (continuum, three-dimensional, eight-node reduced-integration) elements, and element distortion was avoided by employing the enhanced hourglass control formulation. The model's mesh geometry is depicted in Figure 4.

The gasket and the pipe came into regular and tangential contact: The values for the tangential shear modulus  $K_t$  and normal stiffness  $K_n$  were established at 8000 GPa/m and 10,000 GPa/m, respectively. The tangential behavior was designated as penalty while the normal behavior for the interface between the pipe and soil was set to hard contact. Liu [29] suggests that the interaction distribution between the pipe and soil is closely related to their relative stiffness. As a result of the difference in relative stiffness between the pipe bedding and soil, separate tangential friction coefficients were assigned to the pipe-soil interface. Liu and Yang claim that Equation 1 was used to determine the tangential friction coefficient. [3]:

$$\mu = \tan\psi \quad (1)$$

where  $\psi$  is the friction angle.

### 3.4 Case Condition

Two Case Condition:

- (1) Apply typical uprooting imperatives to the encompassing soil surface and chamber and apply omnidirectional relocation imperatives to the soil surface and chamber foot.
- (2) Restrict the pipeline's pivotal and rotational degrees of freedom by imposing boundary conditions on the trunnion of P1 and the chime of P4.

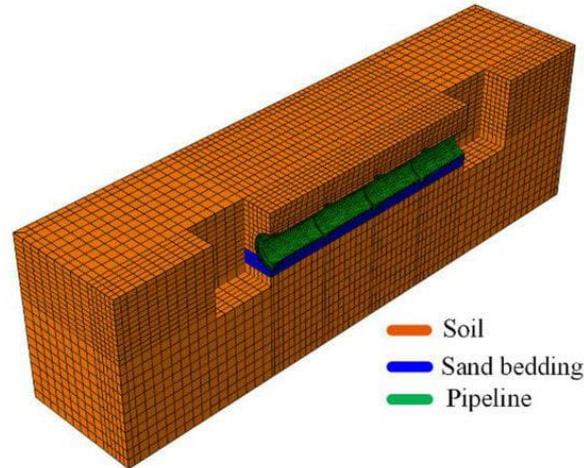


Figure 4. FM. model<sup>8</sup>.

## 4. Results and discussion

Effect of erosion depth on pipeline mechanical properties. The utilization width is  $60^\circ$ , the topsoil weight is 1.0 m, the moving stack is 1.0 MPa, and the collapse occurs at the crest. By changing the thickness of the inner pipe separator, you can reproduce the unique depth of erosion. The effect of erosion depth on pipeline mechanical properties was investigated at 0%, 30% and 60% erosion depths. Long-term operation can cause channel rupture, which can affect the normal operation of the pipeline. To investigate the relationship between pipe breakage risk and erosion depth. In ABAQUS, the best way to understand the push of coordinates associated with a region in different directions at one point is the maximum stretch in the middle. Maximum elongation and the application of four major material damage criteria can be used to assess damage in concrete with normal brittle properties. Concrete pipes are believed to fracture along their length when the maximum life strain exceeds the extreme malleability of concrete. In this way, we take advantage of the significant advantage of prioritizing crowns, spring lines, and those that are not fully established to examine the relationship between line break bet and collapse importance as shown in Figure 5.

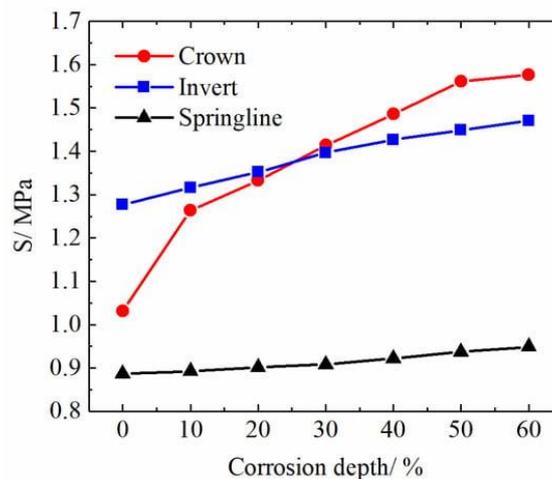


Figure 5. Relationships between the maximum principal stress and corrosion depth<sup>8,5</sup>.

Figure 5 Exceptional advantages in crown, feather line and tuck appear to be closely related to erosion depth. This modification exhibits a higher ultimate critical strain than the crown and spring lines, which have the lowest

mean stress of the non-corrosive tube. As the importance of use increases, the maximal emphasis of turbulent and jumping lines increases steadily, while the maximal emphasis of crowns increases rapidly. The most extreme anterior strains in the crown exceed those in modifications where no erosion is assumed, depth is 30%. These findings demonstrate that erosion has a significant impact on pipes, especially in areas prone to corrosion<sup>8</sup>.

Exceptional advantages in crown, feather line and tuck appear to be closely related to erosion depth. This modification includes a higher peak pressure than the crown or spring line, which has the lowest internal stress in the non-corrosive tube. As the importance of use increases, the maximal emphasis on turbulent and jumping lines increases steadily, while the maximal emphasis on crowns increases rapidly. The maximum life span of the crown exceeds that of the wall, and no erosion is assumed if the erosion depth is 30%. These findings demonstrate that erosion has a significant impact on pipes, especially in areas prone to corrosion. As shown in Figure 6.

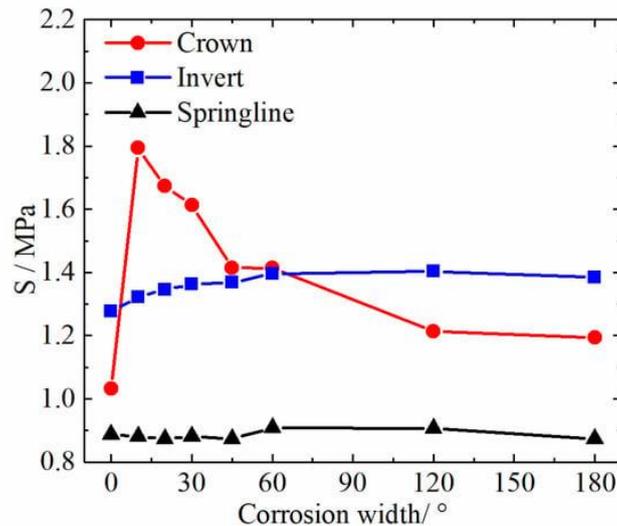


Figure 6. Relationship between greatest central stretch of channeling and erosion width <sup>6,8</sup>.

The relationship between the maximum main flow length and the maximum flow direction of the pipe is negatively related to the erosion width. When the erosion width of a pipe is narrow, the risk of pipe failure increases. To prevent rapid deterioration of the pipe, measures must be taken. The impact of tube tension and corrosion width on pipeline mechanical properties was assessed to determine how motion stack affects pipe splitting. Figure 7 illustrates the separation and dismantling of the main weight at the top of the crown, spring line, and various moving loads underneath, which are significant components.

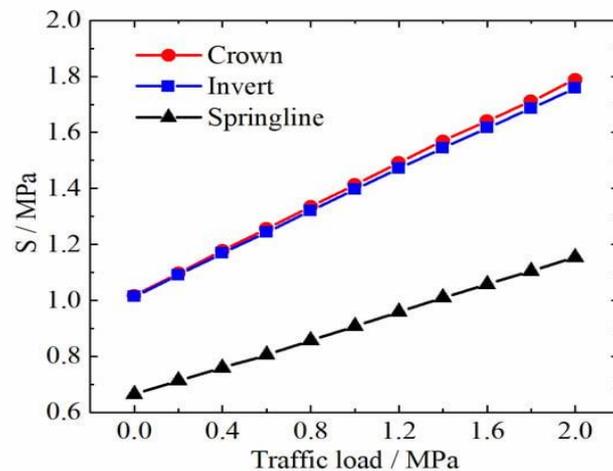


Figure 7. Relationship between maximum principal stress and dynamic load <sup>7,8</sup>

According to Figure 7, there is a direct and positive correlation between move load and the maximum principal stress at the crown, springline, and invert. As move load increases from 0 to 2.0 MPa, the maximum principal stresses at the crown, springline, and invert increase by 1.76, 1.61, and 1.73 times respectively. This finding highlights the significant impact of moving load on maximum principal stress. Therefore, controlling vehicle load is crucial for metropolitan design as it affects the lifespan of civil streets and the functional security of metropolitan pipelines. To investigate the effect of covering depth on pipeline mechanical properties, we calculated topsoil depth values of 1.5 and 2.5 m. Figure 8 illustrates the recombination maxima under the foremost stretch of the crown, jump line, and characteristic deck depth.

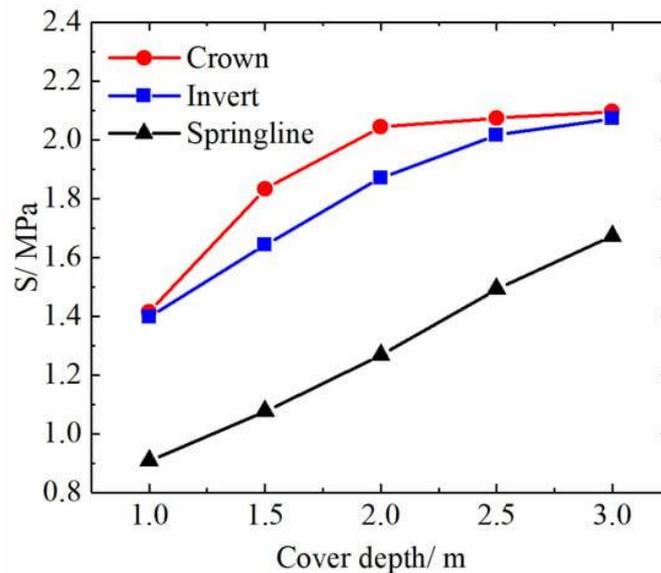


Figure 8. Relationship between cover depth and the maximum principal stress <sup>8,9</sup>

Figure 8 demonstrates how cover profundity is categorically related to the most extreme chief pressure at the spring line. The maximum principal stress at the crown and invert are positively nonlinearly correlated with cover depth. The primary explanation for this is that there are three steps involved in how cover depth affects pipe stress. The maximum principal stress at the crown and invert rises quickly when the cover depth goes from 1 to 2 m, much more so than when it goes from 2 to 3 m. When the cover depth is low, the move load is important, and stress is caused by it. The effects of pressure due to soil strain and move load are the same when cover profundity reaches a specific basic level. Finally, soil pressure, which primarily results in stress, has effects that deteriorate with cover depth. Soil generally dissipates the moving load. As cover depth increases, the effect of soil pressure on pipe stress gradually rises, whereas the effect of move load on pipe stress gradually falls. As a result, the maximum principal stress of the pipe would rise much more slowly as the cover depth rose.

## 5. Conclusions

Numerical demonstrations and tests were used to explore the mechanical properties of the tube and see how different components affect it. We have the following conclusions:

- Recycled total can be used as half replacement for normal 100% total.
- Print quality improved when SPR was included in the concrete mix and 100% of the total was reused. Print quality improved from 9% to 10% on concrete made entirely from recycled materials.
- Cross-sectional flexibility of cements supplied with recycled additives has been found to increase with increasing SPR. Tensile quality increased by 26%, 14%, 1% and 2% respectively for concrete containing 100% recycled additives. SPR.

- The inside of the pipe wall is more susceptible to damage than the outside. At the apex and repositioning, pressure is applied inside the tube divider and at the spring line. However, the opposite is true outside the tube wall.
- In the field of pipe erosion, elastic bending changes unexpectedly. At a pipeline erosion depth of 30%, the strain and strain at the top of the pipe increased by about 50%, and the pressure and strain in the pipe change and tube spring lines increased by about 10% compared to the uncorroded pipeline. % increased. When the utilization importance increases from 0% to 30%, the turbulence inside the tube top increases by about half and the turbulence inside the tube top increases by about 30%. This indicates that erosion on the inside of the pipe divider has a greater impact than on the outside [7]. Corrosion depth is clearly related to the maximum principal stress and hoop strain of the pipe, while corrosion width is inversely related. As the collapse becomes more important, so does the discomfort at the collapse site. Strain and strain decrease initially rapidly (0 to 10°), then rapidly (10 to 45°), and finally gradually (45 to 180°) as erosion latitude increases. 8. Both the hoop load and the highest exceptional gravity scale rapidly as the cover becomes more important or train piles up. It is recommended to periodically inspect ducts with a buried depth greater than 1.5 meters and moving chimneys with a pressure greater than 1.0 MPa to detect pipeline damage.

### Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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