# INFLUENCE OF DEFECT IN THE CONCRETE PILES USING NON-DESTRUCTIVE TESTING

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## ABSTRACT

This paper presents the results of experimental investigation carried out on concrete model piles to study the behaviour of defective piles. This was achieved by employing non-destructive tests using ultrasonic waves. It was found that the reduction in pile stiffness factor is found to be about (26%) when the defect ratio increased from (5%) to (15%). The modulus of elasticity reduction factor as well as the dynamic modulus of elasticity reduction factor increase with the defect ratio.

## الخلاصة

يستعرض هذا البحث النتائج للدراسة المختبرية التي أجريت على نماذج من ركائز خرسانية متضررة ودراسة تصرفها عند تعرضها للاحمال. تم أنجاز ذلك من خلال الفحص غير الاتلافي بواسطة الموجات فوق الصوتية. وقد بينت النتائج بأن مقدار النقصان في معامل جساءة الركيزة (٢٦%) عندما تزداد نسبة الضرر من (٥%) الى (١٥%). كما أن عامل النقصان لمعامل المرونة أضافة الى عامل النقصان بمعامل المرونة الديناميكي يزداد بزيادة نسبة الضرر.

## INTRODUCTION

There is a number of factors, which should be considered in the design of bored piles beyond the routine computation procedures. A review of these factors reveals serious defects, such as, the loss of continuity along the pile length, and the shaft may contain cracks, voids, inclusion, etc. These defects may not affect the pile performance in the short term. However, the long-term behavior may be important, particularly when a pile is subjected to bending stresses (Al-Mosawe and Al-Obaydi, 2002).

Pile defects can be divided broadly into two categories (Poulos, 1997):

- Geotechnical defects, which arise from either a misassessment of the in-situ conditions during design or else from construction-related problems.
- Structural defects, which are generally related to construction and which result in the size, strength and/or stiffness of the pile being less than assumed in design, see Figure (1).

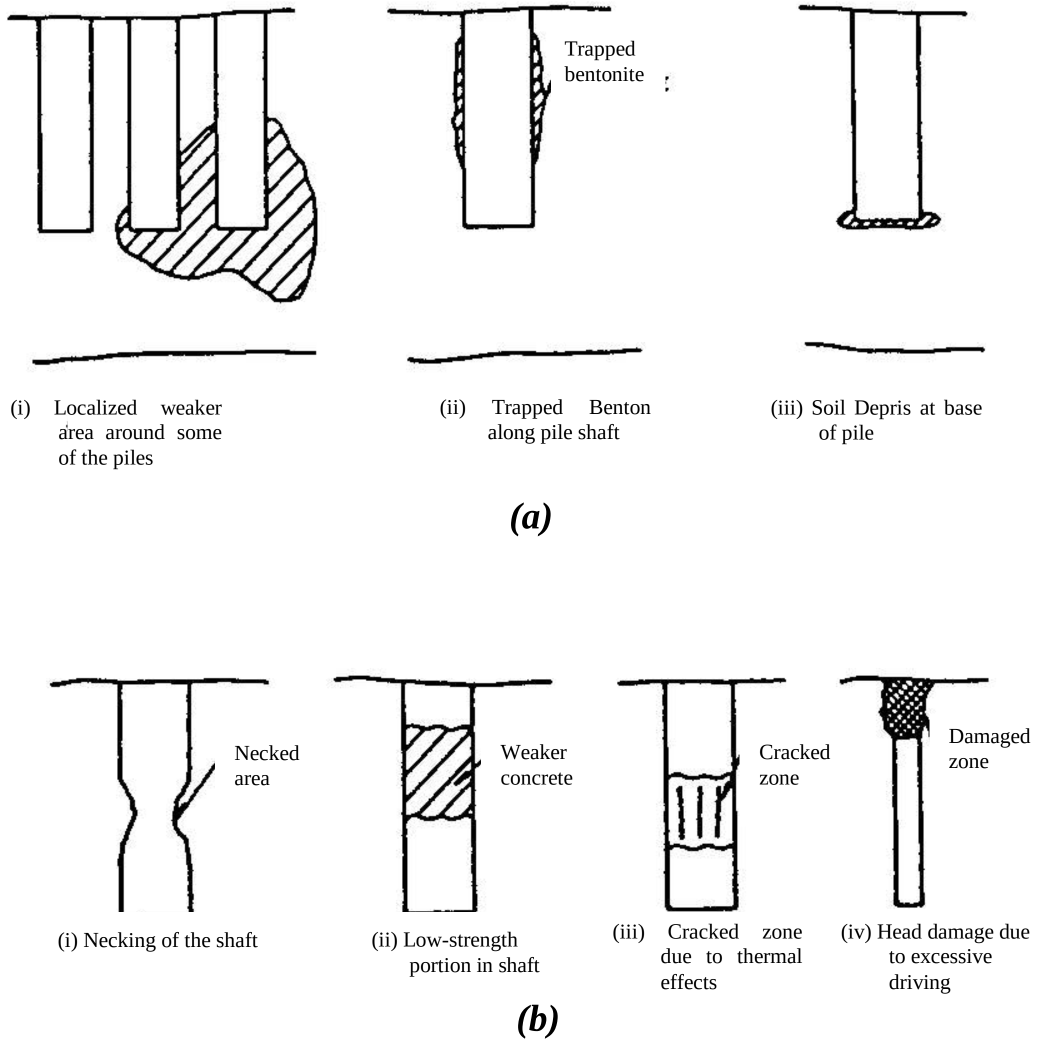


**Fig (1) Examples of (a) Typical Geotechnical Defects; (b) Typical Structural Defects (after Poulos, 1997).**

In many cases in the past, it was assumed that the defective pile would not carry any load and an additional pile or piles have been installed within the group to compensate for the defective pile. Such a procedure is both costly and time-consuming, and it is therefore of some interest to examine whether the defective pile can still function satisfactorily. Therefore, a quick non-destructive method of testing the pile is devised where defects in concrete along the length of the pile could be estimated to a fair degree of accuracy.

## EFFECT OF DEFECTIVE PILE

The presence of defects leads to a reduction in pile axial stiffness; at higher load levels, this reduction can be severe and gives the appearance of a reduction in axial load capacity. If failure of the pile occurs because of structural defect, there is a sudden and dramatic increase in settlement. With geotechnical defects, the apparent loss of load capacity is characterized by a more gradual increase in settlement with increasing load. The ability of the group to redistribute the pile loads from defective pile to intact piles results in a less severe reduction in axial stiffness than the case of a single defective pile. However, the presence of defective piles will generally lead to the development of lateral deflection and rotation of the group, and induces additional bending moments in the piles, even under purely axial applied loading (Poulos, 1997).

## CONCRETE MIX DESIGN

The ACI 211.1-91 method is used for concrete mixes to obtain the required compressive strength. The required compressive strength is 30 $N/mm^2$. Mixing proportions were (1:1.85:1.7), and water - cement ratio (w/c ratio by weight) is 0.5. The water used for mixes was the normal potable water supplied by the municipality, which was used also for curing concrete samples.

### Samples Moulds

Two types of moulds were used for sampling:

- The first type was steel cube moulds (150 mm × 150 mm × 150 mm). These cubic samples were used to find the compressive strength of concrete.

- The second type was a plastic cylindrical mould of a diameter (55 mm), with variable lengths (100 mm, 200 mm, 300 mm, 400 mm, and 500 mm). These samples were used for ultrasonic pulse velocity tests, and model pile tests.

### Ultrasonic Pulse Velocity Test

Ultrasonic pulse velocity test is one of the non-destructive methods to find some of the physical properties of the concrete; the compressive strength, and the dynamic modulus of elasticity of concrete. Non-destructive tests reflect the actual properties of concrete, while the destructive tests (cylinder or cube compression test) carried out on a standard prepared and cured samples, seem to be too far from the actual conditions.

Many researchers tried to suggest a general limit for the ultrasonic wave velocity. One of them was Jones and Gatifield (1963) who suggested limits for the ultrasonic wave velocity in concrete, as given in Table (1):

**Table (1) Velocity a longitudinal ultrasonic pulse for different concrete types (Jones and Gatifield, 1963).**

| *Concrete Type* | *Pulse velocity (km/sec.)* |
|---|---|
| Very Good | More than 4.58 |
| Good | 3.66 – 4.57 |
| Moderate | 3.05 – 3.66 |
| Poor | 2.14 – 3.00 |
| Very Poor | Less than 2.14 |

**Concrete Samples Tested:**

The dimensions of the cylindrical concrete piles used are listed in Table (2). The ultrasonic device (Pundit) was used to measure the ultrasonic wave speed through the concrete samples by using the direct method.

**Table (2) Cylindrical Concrete Samples Tested.**

| *Test No.* | *Length of Pile (mm)* | *Type of Pile* | *Type of Defect* | *Defect Ratio* | *Location of Defect* |
|---|---|---|---|---|---|
| 1 | 100 | Sound | – | – | – |
| 2 | 100 | Defected | Neck | 5% | 1/3 length |
| 3 | 100 | Defected | Neck | 10% | 1/3 length |
| 4 | 100 | Defected | Neck | 15% | 1/3 length |
| 5 | 200 | Sound | – | – | – |
| 6 | 200 | Defected | Neck | 5% | 1/3 length |
| 7 | 200 | Defected | Neck | 10% | 1/3 length |
| 8 | 200 | Defected | Neck | 15% | 1/3 length |
| 9 | 300 | Sound | – | – | – |
| 10 | 300 | Defected | Neck | 5% | 1/3 length |
| 11 | 300 | Defected | Neck | 10% | 1/3 length |
| 12 | 300 | Defected | Neck | 15% | 1/3 length |
| 13 | 300 | Defected | Neck | 5% | 1/2 length |
| 14 | 300 | Defected | Neck | 5% | 2/3 length |
| 15 | 300 | Defected | External void | 5% | 1/3 length |
| 16 | 300 | Defected | External void | 10% | 1/3 length |
| 17 | 300 | Defected | External void | 15% | 1/3 length |
| 18 | 300 | Defected | External void | 5% | 1/2 length |
| 19 | 300 | Defected | External void | 5% | 2/3 length |
| 20 | 300 | Defected | Internal void | 5% | 1/3 length |

| | | | | | |
|---|---|---|---|---|---|
| 21 | 300 | Defected | Internal void | 5% | 1/2 length |
| 22 | 300 | Defected | Internal void | 5% | 1/3 length |
| 23 | 300 | Defected | Void (Internal Void) | 1% | 1/3 length |
| 24 | 300 | Defected | Void (Internal Void) | 1% | 1/2 length |
| 25 | 300 | Defected | Void (Internal Void) | 1% | 2/3 length |
| 26 | 400 | Sound | – | – | – |
| 27 | 400 | Defected | Neck | 5% | 1/3 length |
| 28 | 400 | Defected | Neck | 10% | 1/3 length |
| 29 | 400 | Defected | Neck | 15% | 1/3 length |
| 30 | 500 | Sound | – | – | – |
| 31 | 500 | Defected | Neck | 5% | 1/3 length |
| 32 | 500 | Defected | Neck | 10% | 1/3 length |
| 33 | 500 | Defected | Neck | 15% | 1/3 length |

***Note:***

- Pile diameter (55 mm).
- Defect ratio, is the defect volume compared to the total volume of the pile.

The tests have been performed according to the British standard (BS 1881-Part 203-1086), and to the American standard (ASTMC597-83-1991).

The ultrasonic test was executed as described above, where the longitudinal wave velocity was measured by the direct method, and the type of concrete is determined from (Table (1)). The concrete strength was determined using the following formula (Raouf et al., 1986):

$$f_{cu} = 2.016e^{0.61V} \qquad (1)$$

where:

$f_{cu}$ = Concrete compressive strength (MPa).

V = Wave velocity measured by direct method (km/sec.).

The relation between dynamic modulus of elasticity and the compressive strength of concrete is descried in (CP110: 1972) by the following equation:

$$E_D = 22 + 2.8\sqrt{f_{cu}} \qquad (2)$$

where:

$E_D$ = Dynamic modulus of elasticity for concrete (GPa).

The expression for the static modulus of elasticity of concrete, $E_c$, as mentioned in (BS 8110) is:

$$E_c = 1.25\ E_D - 19 \qquad (3)$$

where:

$E_c$ = Static modulus of elasticity for concrete (GPa).

## Results and Discussion

The results of ultrasonic pulse velocity test are shown in Table (3).

***Table (3) The Results of Ultrasonic Pulse Velocity Test.***

| *Test No.* | *Length of pile (mm)* | *Type of pile* | *Type of Defect* | *Defect Ratio* | *Location of Defect* | *Pulse Velocity (km/sec)* | *Concrete type (see Table (1)* | *$f_{cu}$ (MPa)* | *$E_D \times 10^3$ (MPa)* | *$E_C \times 10^3$ (MPa)* |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 100 | Sound | – | – | – | 4.17 | Good | 25.66 | 36.18 | 26.23 |
| 2 | 100 | Defected | Neck | 5% | 1/3 length | 3.52 | Moderate | 17.23 | 33.62 | 23.03 |
| 3 | 100 | Defected | Neck | 10% | 1/3 length | 2.44 | Poor | 8.90 | 30.35 | 18.94 |
| 4 | 100 | Defected | Neck | 15% | 1/3 length | 1.73 | Very poor | 5.78 | 28.73 | 16.91 |
| 5 | 200 | Sound | – | – | – | 4.17 | Good | 25.60 | 36.17 | 26.21 |
| 6 | 200 | Defected | Neck | 5% | 1/3 length | 3.57 | Moderate | 17.81 | 33.82 | 23.27 |
| 7 | 200 | Defected | Neck | 10% | 1/3 length | 2.59 | Poor | 9.77 | 30.75 | 19.44 |
| 8 | 200 | Defected | Neck | 15% | 1/3 length | 1.87 | Very poor | 6.30 | 29.03 | 17.28 |
| 9 | 300 | Sound | – | – | – | 4.11 | Good | 24.70 | 35.92 | 25.89 |
| 10 | 300 | Defected | Neck | 5% | 1/3 length | 3.57 | Moderate | 17.81 | 33.82 | 23.27 |
| 11 | 300 | Defected | Neck | 10% | 1/3 length | 2.56 | Poor | 9.65 | 30.70 | 19.37 |
| 12 | 300 | Defected | Neck | 15% | 1/3 length | 1.88 | Very poor | 6.35 | 29.06 | 17.32 |
| 13 | 300 | Defected | Neck | 5% | 1/2 length | 3.52 | Moderate | 17.23 | 33.62 | 23.03 |
| 14 | 300 | Defected | Neck | 5% | 2/3 length | 3.49 | Moderate | 16.93 | 33.52 | 22.90 |
| 15 | 300 | Defected | External Void | 5% | 1/3 length | 3.50 | Moderate | 17.05 | 33.56 | 22.95 |
| 16 | 300 | Defected | External Void | 10% | 1/3 length | 2.40 | Poor | 8.70 | 30.26 | 18.82 |
| 17 | 300 | Defected | External Void | 15% | 1/3 length | 1.75 | Very poor | 5.86 | 28.78 | 16.97 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 18 | 300 | Defected | External Void | 5% | 1/2 length | 3.61 | Moderate | 18.23 | 33.96 | 23.44 |
| 19 | 300 | Defected | External Void | 5% | 2/3 length | 3.53 | Moderate | 17.4 | 33.68 | 23.10 |

***Table (3): Continue.***

| *Test No.* | *Length of pile (mm)* | *Type of pile* | *Type of Defect* | *Defect Ratio* | *Location of Defect* | *Pulse Velocity (km/sec)* | *Concrete type (see Table (1)* | *$f_{cu}$ (MPa)* | *$E_D \times 10^3$ (MPa)* | *$E_C \times 10^3$ (MPa)* |
|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 300 | Defected | Internal Void | 5% | 1/3 length | 3.41 | Moderate | 16.14 | 33.25 | 22.56 |
| 21 | 300 | Defected | Internal Void | 5% | 1/2 length | 3.46 | Moderate | 16.64 | 33.42 | 22.78 |
| 22 | 300 | Defected | Internal Void | 5% | 2/3 length | 3.38 | Moderate | 15.85 | 33.15 | 22.43 |
| 23 | 300 | Defected | Internal Defect (Gap in Concrete) | 1% | 1/3 length | 3.99 | Good | 22.98 | 35.42 | 25.28 |
| 24 | 300 | Defected | Internal Defect (Gap in Concrete) | 1% | 1/2 length | 4.00 | Good | 23.13 | 35.47 | 25.33 |
| 25 | 300 | Defected | Internal Defect (Gap in Concrete) | 1% | 2/3 length | 3.95 | Good | 22.40 | 35.25 | 25.07 |
| 26 | 400 | Sound | – | – | – | 4.10 | Good | 24.60 | 35.89 | 25.86 |
| 27 | 400 | Defected | Neck | 5% | 1/3 length | 3.54 | Moderate | 17.50 | 33.71 | 23.14 |
| 28 | 400 | Defected | Neck | 10% | 1/3 length | 2.40 | Poor | 8.72 | 30.27 | 18.84 |
| 29 | 400 | Defected | Neck | 15% | 1/3 length | 1.70 | Very Poor | 5.68 | 28.67 | 16.84 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 30 | 500 | Sound | – | – | – | 4.14 | Good | 25.25 | 36.07 | 26.09 |
| 31 | 500 | Defected | Neck | 5% | 1/3 length | 3.60 | Moderate | 18.12 | 33.92 | 23.40 |
| 32 | 500 | Defected | Neck | 10% | 1/3 length | 2.43 | Poor | 8.90 | 30.35 | 18.94 |
| 33 | 500 | Defected | eck | 15% | 1/3 length | 2.04 | Very Poor | 6.99 | 29.40 | 17.75 |

Whenever there is a defect, the pulse velocity decreases, and this means that the mechanical properties has been affected and transformed to lower strength and lower modulus of elasticity.

The wave velocity for the defect piles was found proportional to defect ratio, and this relation is not affected by the defect type, Table (3).

The results of ultrasonic tests are shown in Figures (2) to (5). In Figure (2), the relation between the modulus of elasticity reduction factor, $r_c$ (where $r_c = (1 - E_{cd}/E_{cs})\times100$, in which $E_{cd}$ is the modulus of elasticity for defected pile and $E_{cs}$ is the modulus of elasticity for sound pile) or the dynamic modulus of elasticity reduction factor, $r_d$ ($r_d = (1 - E_{dd}/E_{ds})\times100$, where $E_{dd}$ is the dynamic modulus of elasticity for defected pile and $E_{ds}$ is the dynamic modulus of elasticity for sound pile) and the defect ratio (the defect volume compared to the total volume of the pile).

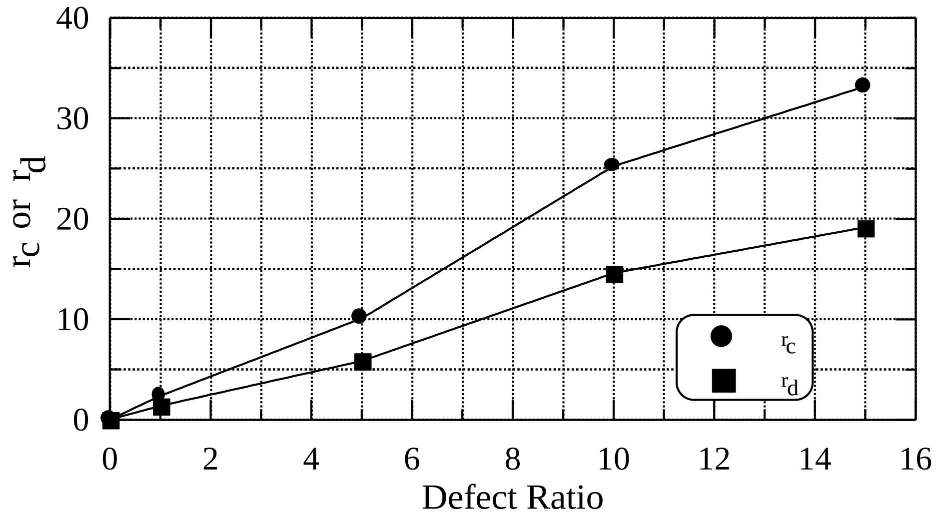


**Fig. (2) The Relation Between Defect Ratio and Reduction Factor in Static or Dynamic Modulus of Elasticity of Concrete.**

It can be noticed that the reduction factors, $r_c$ increases to about (45%) while the factor $r_d$ increases to about (20%) when the defect ratio is (15%).

The presence of voids in defected concrete mass causes a reduction in the pulse velocity, V, of the ultrasonic waves. This is seen in Figure (3) in which the pulse velocity decreases with increase of defect ratio.

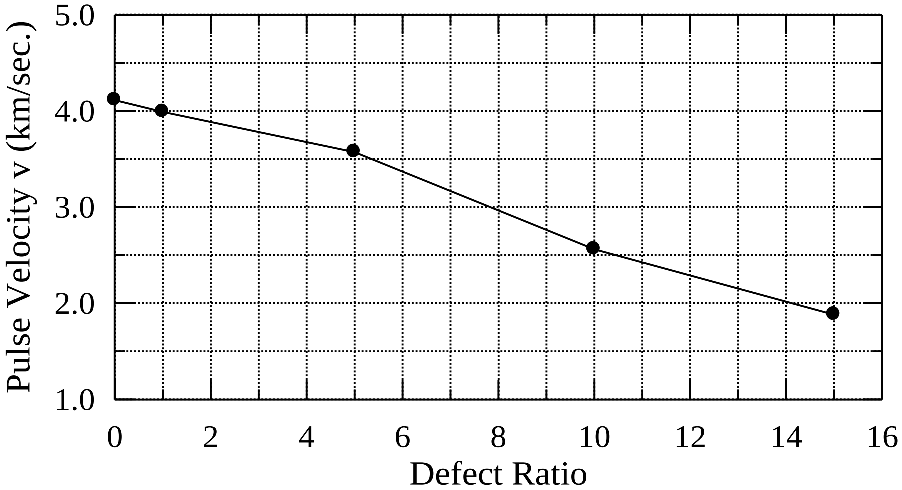


***Fig (3) The Relation Between Defect Ratio and Pulse Velocity.***

The pulse velocity decreases to about (50%) when the defect ratio increase from (5%) to (15%)

Figure (4) shows the relation between the concrete compressive strength reduction factor, (r) (where $r = (1 - f_{cud}/f_{cus})\times 100$, in which $f_{cud}$ is the concrete compressive strength for defective pile and $f_{cus}$ is the concrete compressive strength for sound pile) and the defect ratio. It can be noticed that the factor r increase with the increase of defect ratio. The increase in r is found to be about (45%) when the defect ratio increases from (5%) to (15%).

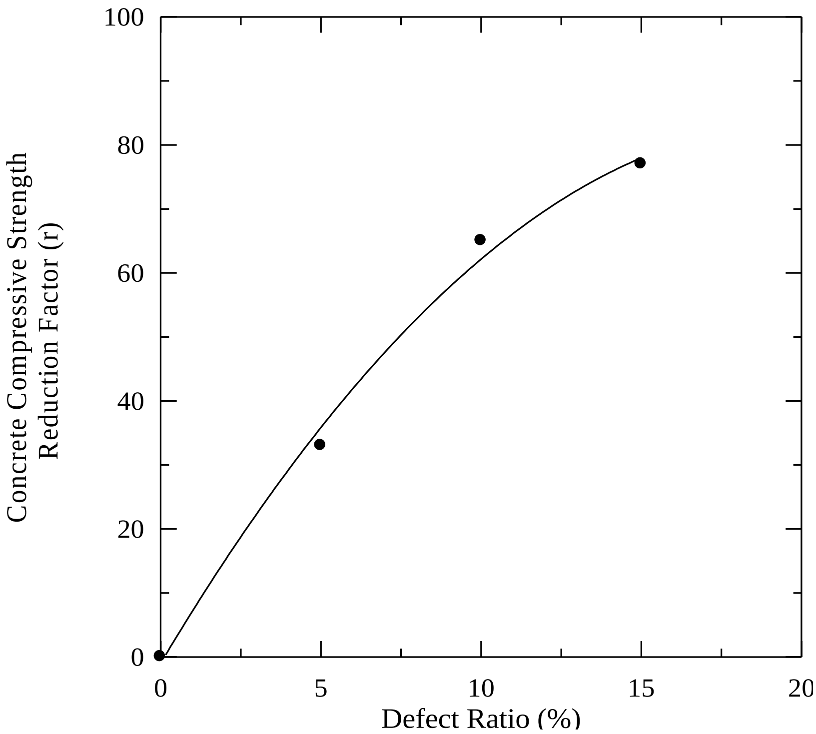


***Fig (4) The Relation Between Defect Ratio and Concrete Compressive Reduction Factor (r).***

Fig (5) shows a relationship between the defect ratio and pile stiffness reduction factor, $R_{ks}$ (where $R_{ks}$ = (stiffness for defected pile / stiffness) for sound pile)×100). The stiffness factor decreases with the increase in defect ratio. The reduction in the factor $R_{ks}$ is found to be about (26%) when the defect ratio increase from (5%) to (15%).

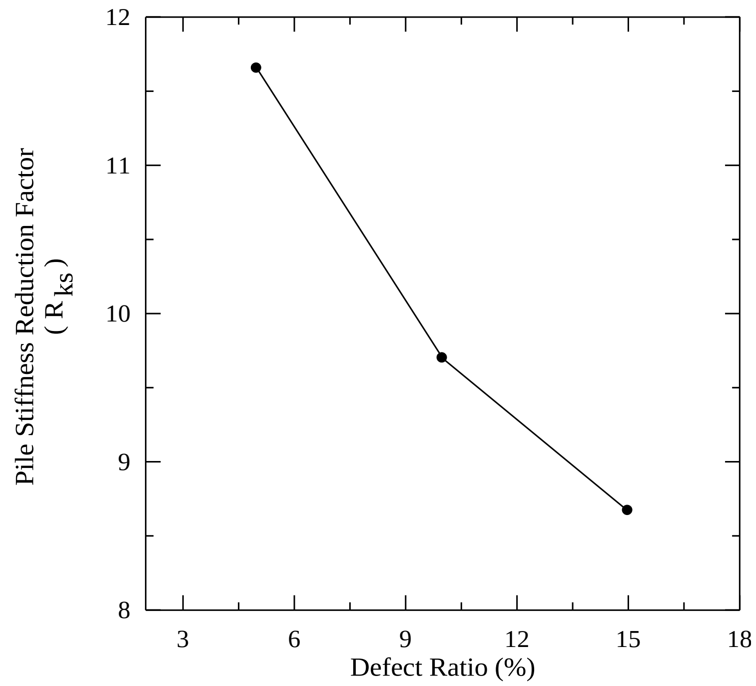


**Fig (5) The Relation Between Defect Ratio and Pile Stiffness Reduction Factor ($R_{ks}$).**

## CONCLUSIONS

The results of this research indicated that when the defect ratio increases from 5 to 15, then:

a- The pulse velocity decreases to about (50%).

b- The reduction factor $r_c$ increases to about (45%), while the factor $r_d$ increases to about (20%).

c- The reduction in pile stiffness factor is found to be about (26%).

d- The decrease in concrete strength is found to be about (45%).

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