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# Effect of Coarse Aggregate Type on Shear Transfer Strength

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The work described in this paper is presented experimentally and analytically (by using finite element method) investigation of the behavior of connections subjected to direct shear stress. 16 push-off specimens were constructed [using four types of coarse aggregate] and tested. The effect of lightweight coarse aggregate type on single direction shear transfer strength, the contribution of the aggregate interlock to resist the shear stress along shear plane, the effect of the reinforcement parameter, the strain in the concrete, slip and lateral separation measurements were studied. To verify the accuracy and applicability of the nonlinear two-dimensional finite element method, comparison between the results of finite element method and those obtained experimentally in this study with results obtained by ACI and PCI equations were carried out. The comparison shows that the finite element method was in total agreement with the experimental.

**Index Terms**— Shear transfer, Coarse aggregate, Concrete mix design, Push-off specimens, Lightweight concrete, Slip, Load failure.

## 1 Introduction

THe Connections are necessary for the transmission of forces from member to member and from member to substructure in precast concrete construction.

Similar situations also exist in cast-in-place concrete construction at locations where construction joints are necessary. These connections and construction joints are structural elements as essential as the individual 1oad-carrying members of the structure. The performance of the completed structure depends as much as the performance of the connections as on the performance of the main members. In order to develop full capacity of the main members, the connections and joints must be designed and fabricated in such a manner as to transmit the appropriate forces with an adequate factor of safety and with a minimum of cracking and spalling at service loads [1].

In this study, four types of coarse aggregate are used for pouring concrete of sixteen specimens (natural gravel, crushed sand-lime brick, crushed ordinary brick and crushed thermostone block). The test specimens were of the push-off type. The main objectives of this study are:

1. Evaluating experimentally the shear transfer strength of the specimens with and without reinforcement across the shear plane.
2. Examining the applicability of the shear friction theory to the evaluation of the shear transfer strength.
3. Determining the influence of reinforcement parameter on the shear transfer strength.
4. Comparing the results obtained by the finite element method with those obtained experimentally and with the proposal of per ACI and PCI.

Mattock and Wang (1984) [2], studied the correlation is made between the shear strength computed by ACI Building Code (ACI 318-77) alongside recommendations of the AC1 Committee 426, from tests by apply axial compressive stress of up to 0.7fc on 38 specimens of reinforced concrete members, the shear and diagonal tension, and shear strength were calculated. The techniques for estimation of shear strength were observed to be traditionalist for all specimens; and exceptionally preservationist for some specimens. The ACI Building Code methods for design of members which subjected to axial force are Adjustment to be more safe against shear failure.

Al Sharea (1999)[3], presented an experimentally and analytically investigation on the behavior of connection subjected to direct shar stress and normal compressive stress acting parallel and across the shear plane respectively. Fifteen modified push-off specimens were constructed (using Abu-Gahr crushed limestone as coarse aggregate) and tested. The variable steadied was the use of only plane concrete existing in the vicinity of shear plane to estimate the concrete contribution by aggregate interlock to the ultimate shear transfer capacity. Also, the influence of normal compressive stress across the shear plane and the role of the parallel reinforcement in resisting shear were studied.

## 2 EXPERIMENTAL PROGRAM

### 2.1 Materials

The materials which used in this research work are locally available. The materials include ordinary Portland cement, silica sand, natural gravel, lightweight coarse aggregate, water and steel reinforcement. three types of the lightweight materials which brought from the waste of local factories of (sand-lime brick, ordinary brick and thermostone block). The lightweight materials were crushed in angular with adequate amount of elongated of and flaky particles. The grading of these lightweight materials arranged to satisfy the ASTM C330 requirements[4], and the grading of used sand and gravel were satisfied the ASTM C33 requirements[5], as shown in Fig.1. Some tested properties of used materials are shown in Table 1.

### 2.2 Concrete Mix Prorortion

Four types of concrete mixes were made by using same materials of natural sand as fine aggregate, ordinary Portland cement, water and the difference by using four types of coarse

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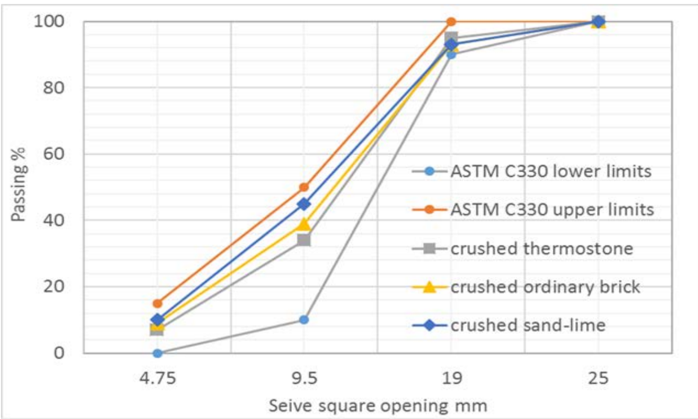
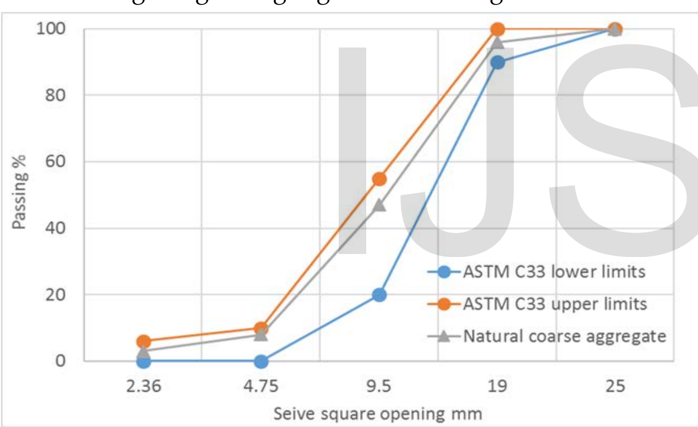
aggregate as following:
1-Natural gravel. 2-Crushed sand-lime brick.
3-Crushed ordinary brick. 4-Crushed thermostone block.

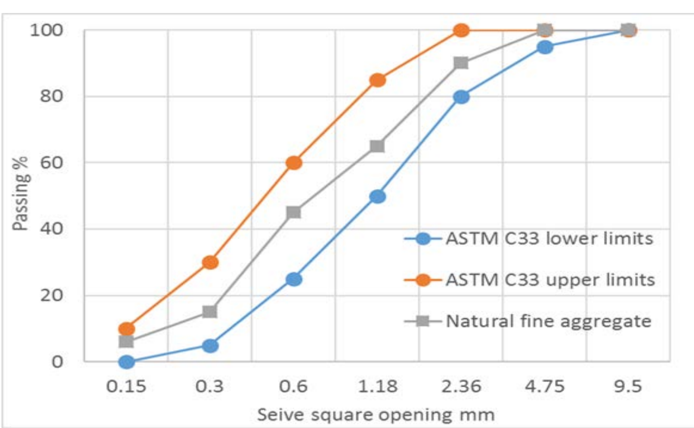
All types of aggregate were washed to remove dust. Eight trial mixes were made, two for each type. The water – cement ratio was changed to cover a wide range of strength and workability. The used mixes and the corresponding water – cement ratios and compressive strengths are presented in Table 2.




a. Grading of lightweight gravel according to ACTM C330




b. Grading of gravel according to ACTM C33




c. Grading of sand according to ACTM C33

Fig.1 Grading of fine and coarse aggregates

TABLE 1 PROPERTIES OF USED MATERIALS

| Aggregate | | | |
|---|---|---|---|
| material | Absorption % | Bulk specific gravity | Dry density Kg/m3 |
| natural Sand | 2.72 | 2.58 | 1756 |
| natural gravel | 2.12 | 2.65 | 1693 |
| sand-lime aggregate | 10.2 | 2.31 | 1125 |
| ordinary brick aggregate | 14.6 | 2.37 | 850 |
| thermoston aggregate | 18.4 | 2.18 | 450 |
| Steel reinforcement | | | |
| diameter (mm) | Modulus of elasticity Es (Mpa) | yeild stress fy (Mpa) | ultimate strength fu (Mpa) |
| 5 | 196 | 395 | 670 |
| 10 | 202 | 410 | 735 |
| 12 | 205 | 415 | 720 |

TABLE 2 MIXES DESIGN CHARACTERISTICS

| Mix No. | Type of coarse aggregate | Cement Content (Kg/m3) | Mix proportion | | | water - Cement ratio | Slump (mm) | f'c (Mpa) 28-day |
|---|---|---|---|---|---|---|---|---|
| | | | cement | Sand | coarse aggregate | | | |
| 1 | natural gravel | 400 | 1 | 1.52 | 3.52 | 0.5 | 40 | 32.14 |
| 2 | crushed sand-lime brick | 420 | 1 | 1.53 | 3.63 | 0.48 | 35 | 27.48 |
| 3 | crushed ordinary brick | 420 | 1 | 1.54 | 3.62 | 0.48 | 40 | 30.87 |
| 4 | crushed thermostone block | 430 | 1 | 1.52 | 3.52 | 0.46 | 30 | 27.32 |

### 2.3 Details of Test Specimens

The 16 tested specimens had the dimensions (150 mm depth, 500 mm length and 300 mm width) as shown in Fig.2.

The tested specimens were of the push-off type with a shear plane of (375 cm2). When loaded as indicated by arrows, shear without moment is produced in the shear plane. The steel reinforcement crossing the shear plane was in the form welded closed stirrups. The main parameters other than the type of coarse aggregate were the amount of shear steel reinforcement. The arrangements are shown in Table 3.

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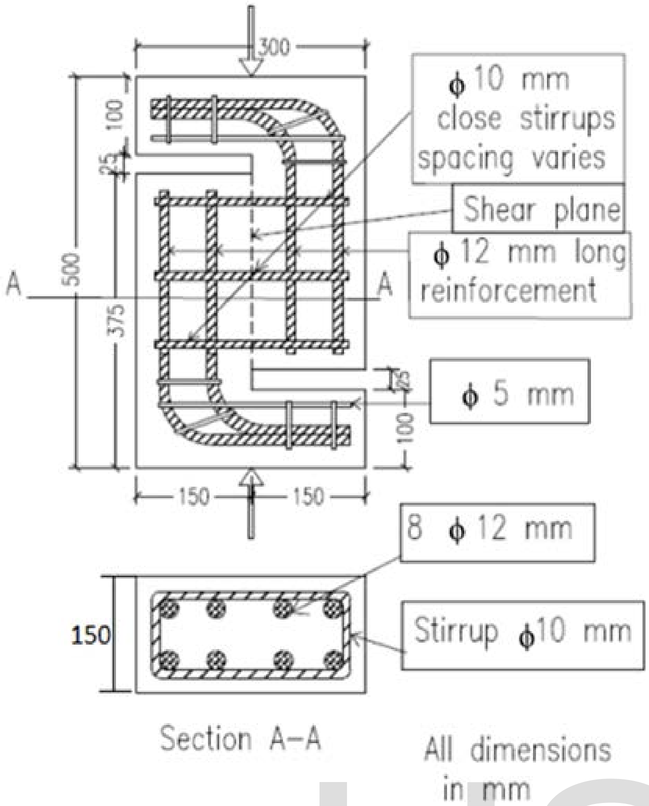


Fig.2 specimens details

TABLE 3 DETAILS OF TEST SPECIMENS

| Spec. Symboe | Type of coarse aggregate | Shear Reinf. Φ 10 mm | Long Reinf. Φ 12 mm |
|---|---|---|---|
| SA0 | natural gravel | --- | 4 |
| SA1 | | 2 | 4 |
| SA2 | | 4 | 4 |
| SA3 | | 6 | 4 |
| SB0 | crushed sand-lime brick | --- | 4 |
| SB1 | | 2 | 4 |
| SB2 | | 4 | 4 |
| SB3 | | 6 | 4 |
| SC0 | crushed ordinary brick | --- | 4 |
| SC1 | | 2 | 4 |
| SC2 | | 4 | 4 |
| SC3 | | 6 | 4 |
| SD0 | crushed thermostone block | --- | 4 |
| SD1 | | 2 | 4 |
| SD2 | | 4 | 4 |
| SD3 | | 6 | 4 |

### 2.4 Fabrication

Each specimen was cast horizontally in one piece, oriented as indicated by the section of Fig.2.

For each group of specimens, which casted in same time by using the one concrete mix, nine concrete cylinders were casted to be tested for compressive strength f'c, tensile strength ft, modulus of elasticity and Poisson ratio and three tensile prisms were casted to be tested for modulus of rupture fcr. The results of the test are shown in Table 4).

TABLE 4 CONCRETE PROPERTIES

| Spec. Symboe | ρ fy | f'c | ft | fcr | v | slump | Ec | Yd |
|---|---|---|---|---|---|---|---|---|
| SA0 | 0 | 31.5 | 2.81 | 2.36 | 0.16 | 50 | 27350 | 2530 |
| SA1 | 1.72 | 31.5 | 2.81 | 2.36 | 0.16 | 50 | 27350 | 2530 |
| SA2 | 3.43 | 31.5 | 2.81 | 2.36 | 0.16 | 50 | 27350 | 2530 |
| SA3 | 5.15 | 31.5 | 2.81 | 2.36 | 0.16 | 50 | 27350 | 2530 |
| SB0 | 0 | 30.8 | 2.35 | 2.15 | 0.21 | 25 | 22824 | 1923 |
| SB1 | 1.72 | 30.8 | 2.35 | 2.15 | 0.21 | 25 | 22824 | 1923 |
| SB2 | 3.43 | 30.8 | 2.35 | 2.15 | 0.21 | 25 | 22824 | 1923 |
| SB3 | 5.15 | 30.8 | 2.35 | 2.15 | 0.21 | 25 | 22824 | 1923 |
| SC0 | 0 | 31.1 | 2.51 | 2.28 | 0.18 | 40 | 21827 | 1732 |
| SC1 | 1.72 | 31.1 | 2.51 | 2.28 | 0.18 | 40 | 21827 | 1732 |
| SC2 | 3.43 | 31.1 | 2.51 | 2.28 | 0.18 | 40 | 21827 | 1732 |
| SC3 | 5.15 | 31.1 | 2.51 | 2.28 | 0.18 | 40 | 21827 | 1732 |
| SD0 | 0 | 30.2 | 2.14 | 1.98 | 0.23 | 30 | 20153 | 1255 |
| SD1 | 1.72 | 30.2 | 2.14 | 1.98 | 0.23 | 30 | 20153 | 1255 |
| SD2 | 3.43 | 30.2 | 2.14 | 1.98 | 0.23 | 30 | 20153 | 1255 |
| SD3 | 5.15 | 30.2 | 2.14 | 1.98 | 0.23 | 30 | 20153 | 1255 |

## 3 TEST PROCEDURE

Specimens were subjected to a continuously increasing load by using 200 ton-torsfe's universal testing machine until failure occurred, with small pauses as necessary to mark any crack which may have occurred, and to record strain, lateral separation, spalling, slip, crack width. The ultimate load was defined as the maximum load that could be carried by specimen. Arrangement of the test are shown in Fig.3.

## 4 FINITE ELEMENT METHOD

By developing program using Fortran language based on Two-dimensional nonlinear finite element method, nine nodes isoperimetric element for concrete, three nodes bar element for steel reinforcement and each node have two degrees of freedom. Full bond connection assumed between steel reinforcement and concrete by connect the nodes of bar element with nodes of isoperimetric element of the same positions.

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Fig. 3 Arrangements for test of push-off specimen

## 5 ACI CODE

ACI 318-95 [6], allow the design when shear – friction is perpendicular to shear plane, shear strength $V_U$ shall be computed by

$$V_U = A_{vf}.f_v.\mu \qquad (1)$$ and,

$$V_u = \emptyset.A_{vf}.f_v.\mu \qquad (2)$$

Where

$V_U$: factored shear strength

$\emptyset$: strength reduction factor=0.85

μ: coefficent of friction

equation (2) may be rewritten in terms of the shear stress Vu as:

$$Vu=\emptyset\,.f_y.\mu\,.\rho \qquad (3)$$

When an externally applied force acts across the shear plane ($\sigma_{nx}$ ), the (3) becomes:

$$Vu=(\emptyset\,.\,\rho f_y+\sigma_{nx})\ \mu \qquad (4)$$

According to recommendation of ACI code the coefficient of friction μ shall be taken 1.4 for normal weight concrete and 1.05 for lightweight concrete of this work.

## 6 PCI DESIGN HANDBOOK

The PCI design handbook [7], suggests to modify The ACI equation as follows:

$$v_u = (\emptyset\,.\,\rho f_y.+\sigma_{nx})\,\mu\,(\frac{2.1}{\emptyset.\,\rho f_y+\sigma_{nx}}+0.5)$$

## 7 RESULTS

The test results in term of first crack load (FCL), failure load (FL), first and maximum crack width are shown in Table 5.

TABLE 5 TEST RESULTS OF THE PUSH-OFF SPECIMENS

| Spec. No. | FCL kN | FL kN | FCL/FL % | First crack Width mm | Max. crack Width mm |
|---|---|---|---|---|---|
| SA0 | 139.23 | 154.95 | 0.9 | 0.08 | Separation of the halves |
| SA1 | 123.42 | 218.36 | 0.57 | 0.08 | 0.89 |
| SA2 | 115.53 | 270.48 | 0.43 | 0.08 | 0.84 |
| SA3 | 101.96 | 313.2 | 0.33 | 0.07 | 0.81 |
| SB0 | 115.64 | 120.37 | 0.96 | 0.1 | Separation of the halves |
| SB1 | 110.57 | 170.25 | 0.67 | 0.09 | 1.02 |
| SB2 | 98.75 | 219.37 | 0.45 | 0.09 | 0.92 |
| SB3 | 90.87 | 255.75 | 0.36 | 0.08 | 0.85 |
| SC0 | 135.21 | 147 | 0.92 | 0.1 | Separation of the halves |
| SC1 | 120.51 | 211.16 | 0.57 | 0.09 | 0.94 |
| SC2 | 113.73 | 261.93 | 0.43 | 0.08 | 0.88 |
| SC3 | 97.35 | 304.2 | 0.32 | 0.08 | 0.84 |
| SD0 | 95.95 | 100.23 | 0.96 | 0.13 | Separation of the halves |
| SD1 | 91.53 | 145.72 | 0.63 | 0.11 | 1.12 |
| SD2 | 84.32 | 190.34 | 0.44 | 0.09 | 0.97 |
| SD3 | 75.74 | 232.51 | 0.33 | 0.09 | 0.87 |

For specimens, S (A, B, C and D) 0, the first crack occurred at about (91-98) % of the ultimate strength. For S (A, B, C and D) 1,2 and 3, the first crack occurred at about (58-67) %, (43-46) % and (32-33) % of the ultimate strength respectively. Also, it can be noticed that crack width is reduced, as ρfy increased and also crack with normal concrete is less than lightweight concrete.

The test results of slip at FCL, FL and load required to establish bearing between particles (Pb) are shown in Table 6.

From table 6, It can be seen that the slip for normal concrete is nearly constant at ultimate shear strength, but for lightweight concrete the slip at ultimate shear decrease as reinforcement parameter increases

Table 7, showed the comparison of Vu from FEM with Vu tested and with ACI, and PCI equations.

TABLE 6 VALUES OF SLIP AT VARIOUS STAGE OF LOADING

| Spec. No. | Slip at FCL mm | Slip at FL mm | Pb kN | Slip at Pb load mm |
|---|---|---|---|---|
| SA0 | 1.24 | - | 50.53 | 0.73 |
| SA1 | 0.5 | 1.85 | - | - |
| SA2 | 0.18 | 1.82 | - | - |
| SA3 | 0.11 | 1.81 | - | - |
| SB0 | 1.75 | - | 25.74 | 0.51 |
| SB1 | 0.78 | 2.34 | - | - |
| SB2 | 0.25 | 2.28 | - | - |
| SB3 | 0.18 | 1.95 | - | - |
| SC0 | 1.21 | - | 42.86 | 0.68 |
| SC1 | 0.46 | 2.25 | - | - |
| SC2 | 0.16 | 2.02 | - | - |
| SC3 | 0.1 | 1.76 | - | - |
| SD0 | 1.77 | - | 20.17 | 0.7 |
| SD1 | 0.83 | 2.83 | - | - |
| SD2 | 0.34 | 2.34 | - | - |
| SD3 | 0.1 | 2.01 | - | - |

TABLE 7 COMPARISON OF $V_U$ FEM WITH $V_U$ TEST AND WITH ACI, AND PCI EQUATIONS

| Spec. No. | Vu FEM MPa | Vu test MPa | Vu calc. ACI MPa | Vu calc. PCI MPa |
|---|---|---|---|---|
| SA0 | 3.91 | 4.13 | - | - |
| SA1 | 5.66 | 5.82 | 2.41 | 3.96 |
| SA2 | 7.15 | 7.21 | 4.81 | 4.98 |
| SA3 | 8.14 | 8.35 | 7.21 | 6.01 |
| SB0 | 3.08 | 3.21 | - | - |
| SB1 | 4.42 | 4.54 | 1.81 | 2.97 |
| SB2 | 6.13 | 5.85 | 3.61 | 3.74 |
| SB3 | 7.52 | 6.82 | 5.41 | 4.51 |
| SC0 | 3.75 | 3.92 | - | - |
| SC1 | 5.42 | 5.63 | 1.81 | 2.97 |
| SC2 | 6.86 | 6.98 | 3.61 | 3.74 |
| SC3 | 8.31 | 8.11 | 5.41 | 4.51 |
| SD0 | 2.98 | 2.67 | - | - |
| SD1 | 3.59 | 3.84 | 1.81 | 2.97 |
| SD2 | 5.42 | 5.08 | 3.61 | 3.74 |
| SD3 | 6.73 | 6.2 | 5.41 | 4.51 |

## 8 CONCLUSION

1. The shear transfer strength of lightweight concrete is less than that of normal weight concrete of the same compressive strength.
2. The type of course aggregate affects mainly shear strength due to different in roughness and bound strength between mortar and the aggregate particles.
3. The deformation slip and lateral separation decrease with rising value of $\rho f_y$.
4. The finite element method results were much closer to the test strength than ACI and PCI equations.

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