DOWEL ACTION BETWEEN TWO CONCRETES

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ABSTRACT

This paper reports eight tests in which in-plane shear forces are applied across the joint between two different concretes forming a composite action. Shear can be transmitted across the joint either by interlocking of the aggregate particles protruding from each face or by shearing of the reinforcement crossing the joint. Tests are conducted on initially cracked specimens by depending only on dowel action. The results of the tests are compared with theoretical results of the exponential equation presented by Millard and Johnson. The computer program of Al-Shaarbaf using the nonlinear behavior of concrete is used to perform the analysis with inclusion of the exponential equation for dowel action in the interface layer. The program uses 20-node brick elements with embedded bar elements. This program is also applied to Hofbeck et al. tests. The comparison shows that the experimental and the analytical results give good agreement where the difference between the two is between (2.5-5)% . The use of the exponential equation gives good results when the concrete is assumed to be initially cracked as in construction joints.

الفعل الوتدي بين خرسانتين

ألخلاصة

تم أجراء ثمانية فحوص سلطت فيها قوى القص عبر الشق أو الشرخ الموجود بين خرسانتين مختلفتين مكونتين للفعل المركب. يمكن نقل القص عبر الشق أما بتداخل حبيبات الركام البارزة من كل من وجهي الشق أو من خلال التسليح العابر للشق. أجريت الفحوص على نماذج متشققة ومعتمدة فقط على الفعل الوتدي. قورنت نتائج الفحوصات مع نتائج نظرية لمعادلة أسية قدمت من قبل ميلارد وجونسون. ولغرض أجراء التحليل الأنشائي فقد تم استخدام برنامج الشعرباف الآخذ بنظر الأعتبار ا

السلوك اللاخطي للكونكريت وبالاعتماد على المعادلة ألأسية للفعل االوتدي للطبقة البينية. تم تطبيق البرنامج الذي يستعمل عناصر طابوقية ذات 20 عقدة مع عناصر قضبان مطمورة على فحوصات هوفبك وجماعته. قورنت النتائج التحليلية الحالية مع نتائج فحص هوفبك وجماعته وقد أعطت النتائج العملية والتحليلية مقارنة جيدة. أن أستعمال المعادلة ألأسية يعطي نتائج للطبقة البينية يعطي نتائج جيدة فقط حينما تكون الخرسانة متشققة مسبقا كما في المفاصل الأنشائية.

KEYWORDS

Composite construction, Construction joints, Shear transfer, Dowel action.

INTRODUCTION

When two concretes one over the other are cast at different times, a construction joint will exist. The medium which is separating the two dissimilar concretes during the assemblage of precast and cast – in - place

concrete in composite construction is called interface. The highly stressed interface is a potential failure plane, through which shear stress is transferred, and direct shear failure may occur. Therefore an adequate reinforcement across such a plane must be provided to prevent such type of failure. Because of the external tension, shrinkage, or accidental causes a crack may form along such a plane even before shear occurs **(13).** Therefore the design approach should consider the interface shear capacities for both the initially uncracked and initially cracked concrete. It is commonly believed that a distinct difference exists in shear transfer behavior between initially uncracked and cracked specimens. The present work chooses the initially cracked model of interface because it is well believed that initially cracked specimens are governed largely by the shear- slip characteristics of the cracked plane **(14).**The interface area between different concretes in composite structures represents an unknown medium especially in shear transfer phenomenon. Therefore so many studies were done in this region especially the tests which were done by Grossfield and Birnstiel **(7)** on T-beams with precast webs and cast-in-place flanges. The other difficulty is how to model the behavior of concrete under the existence of cracks and the assumption of initially cracked or uncracked specimen. However, Table (1) shows the available models used to represent shear transfer through interfaces in initially cracked or uncracked interfaces.

When load is applied, slip occurs between the two surfaces of concrete especially when there is no enough reinforcement bars connecting them together. The shear transfer is done by two mechanisms: aggregate interlock and dowel action **(12)**. In an initially uncracked model most of the shear force is carried by aggregate interlock **(6).** In an initially cracked model, the predominant factor in transferring shear through interface is by dowel action. Therefore the contribution of the bars in shear transfer is by their shear modulus which must be studied and evaluated **(18).**

Table (1) Models of shear transfer in interfaces

Model or theory used	Author
(1)Shear friction concepts (cracked and uncracked) -(relying on monolithic action)	ACI-code 318-2005 **(1)**
(2)Increasing roughness and interface-reinforcement Percentage ratio (cracked and uncracked).	Paulay et al.1974 **(20)** and Patnaik 2000 **(19)**
(3)Increasing concrete strength (cracked and uncracked)	Walraven et al. 1987 **(21)**
(4)Strut-and-tie concept (uncracked)	Hwang and Lee 1999 **(10)**
(5)Softened strut-and-tie concept (uncracked)	Hwang and Lee 2000 **(11)**
(6)Softened truss theory (cracked)	Hsu et al. 1987 **(9)**
(7)Shear-slip characteristics (cracked)	Mattock and Hawkins 1972 **(14)**
(8)Smooth interface model	Patnaik 2001 **(17)**
(9)Hybrid type finite element model	Barbieri et al. 2003 **(3)**
(10)Elastic-plastic model (dowel action)	Millard and Johnson 1984,1985 **(15)** **(16)**
(11)Two-phase model (aggregate interlock)	Walraven and Reinhardt 1981 **(22)**
(12) Isoparametric interface element model	Beer G. 1985 **(4)**

SHEAR MODULUS OF DOWEL BARS

Millard and Jonhson **(15, 16)** proposed two equations for the dowel force by considering the dowel bar as a beam on an elastic foundation. One of these equations is for linear behavior Fd_1 and the other is Fd_2 for nonlinear behavior of materials, respectively as follows:

$$Fd_1 = 0.166\Delta_s G_f^{0.75}\Phi^{1.75}E_s^{0.25} \qquad \text{….. (1)}$$

$$Fd_2 = Fdu_2(1 - e^{\frac{k_i \Delta s}{Fdu_2}}) \qquad \text{….. (2)}$$

where the constant term is dimensionless and :

Δs is the shear displacement across the interface.

G_f is the foundation modulus for concrete and is given by:

$$G_f = 126.26\sqrt{f_{cu}} \quad \text{(MPa)} \qquad \text{…..(3)}$$

Φ is the diameter of the bar.

E_s is the elastic modulus of steel.

By dividing Eq. (1) by Δs, the stiffness of the dowel bar k_i is governed by:

$$k_i = 0.166 G_f^{0.75}\Phi^{1.75}E_s^{0.25} \qquad \text{…… (4)}$$

When the two sides of Eq. (1) are divided by $P.B_g$, where P is the pitch or the spacing between the bars and B_g is the width of the upper part of the precast girder which gives the lower face of the interface, the following equation will be obtained:

$$\frac{Fd_1}{P.B_g} = \left[\frac{0.166 G_f^{\,0.75} \Phi^{1.75} E_s^{\,0.25}}{P.B_g}\right] * \Delta s \qquad \text{..... (5)}$$

Multiplying and dividing the right-hand side of Eq. (5) by t_i , the thickness of the interface element, the following expression is obtained:

$$\underbrace{\frac{Fd_1}{P.B_g}}_{ShearStress\,\tau} = \underbrace{\left[\frac{0.166 G_f^{\,0.75} \Phi^{1.75} E_s^{\,0.25} t_i}{P.B_g}\right]}_{ShearModulus\,G_{DOWEL}} \underbrace{\left[\frac{\Delta s}{t_i}\right]}_{ShearStrain(\gamma)} \qquad \text{.... (6)}$$

Therefore, $G_{DOWEL} = \dfrac{0.166 G_f^{\,0.75} \Phi^{1.75} E_s^{\,0.25} t_i}{P.B_g}$ .....(7)

Or, $G_{DOWEL} = k_i \dfrac{t_i}{P.B_g}$ ...... (8)

where $k_i = 0.166 G_f^{\,0.75} \Phi^{1.75} E_s^{\,0.25}$ as in Eq.(4). However, the high stress concentration in the concrete supporting the bar results in a nonlinear behavior, so that only the initial dowel stiffness can be predicted when using this equation **(16).** If Eq. (2) is differentiated with respect to Δs , the following equation will be obtained:

$$\frac{dFd_2}{d\Delta s} = -k_i e^{\frac{k_i \Delta s}{Fdu_2}} \qquad \text{..... (9)}$$

$\dfrac{dFd_2}{d\Delta s}$ is the nonlinear stiffness of the dowel bar which will be named k_{in} to distinguish it from the initial stiffness k_i . Here k_{in} is given by:

$$k_{in} = -k_i e^{\frac{k_i \Delta s}{Fdu_2}} \qquad \text{..... (10)}$$

The nonlinear shear modulus of the dowel bar (G_{DOWELN}) can be written as:

$$G_{DOWELN} = k_{in} \frac{t_i}{P.B_g} \qquad \text{.... (11)}$$

$$\text{Or, } G_{DOWELN} = -k_i e^{\frac{k_i \Delta s}{Fdu_2}} * \frac{t_i}{P.B_g} \qquad \text{..... (12)}$$

where Fdu_2 is the ultimate shear force in the bar at which the ultimate bending moment (Mp) is reached. Failure occurs either by tensile splitting of the concrete or when the bar reaches its ultimate bending moment (Mp).

$$Fdu_2 = 1.3\Phi^2 f_{cu}^{\ 0.5} \sqrt{f_y (1-\alpha^2)} \qquad \text{..... (13)}$$

where f_{cu} is the cube compressive strength of concrete, and α is the ratio of the axial stress to the yield stress of reinforcing steel ($\alpha = f_s / f_y$).

EXPERIMENTAL WORK

Millard and Johnson made so many test trials to investigate the effects of aggregate interlock and dowel action. In their study, the governed curves were representing aggregate interlock results, dowel action results and a combination between the two in two papers (15) and (16). They suggested a nonlinear Equation (2) to represent the relationship between shear load transferred through interface and the slip. This equation is used in the present work, and to check its validity an experimental work is conducted in this study through a series of tests.

The presented work is built on the assumption that the model is initially cracked, therefore the tests done are with an initial crack. These tests and the equation used in the program are for the dowel action effect only because as crack initiates aggregate interlock effect will be low or having a value approaching to zero.

TEST SPECIMENS

The samples tested were rectangular concrete prisms having dimensions 200 mm x 200 mm in section and 500 mm length. The prism was divided into three parts through the use of a separation layer of thin polythene sheeting to eliminate aggregate interlock effects.

Four bars were used to represent the effect of dowel action which are erected in positions in the mold at 5 cms from each side. Details of the specimen shape and dimensions are shown in Fig. (1) and Photo (1).

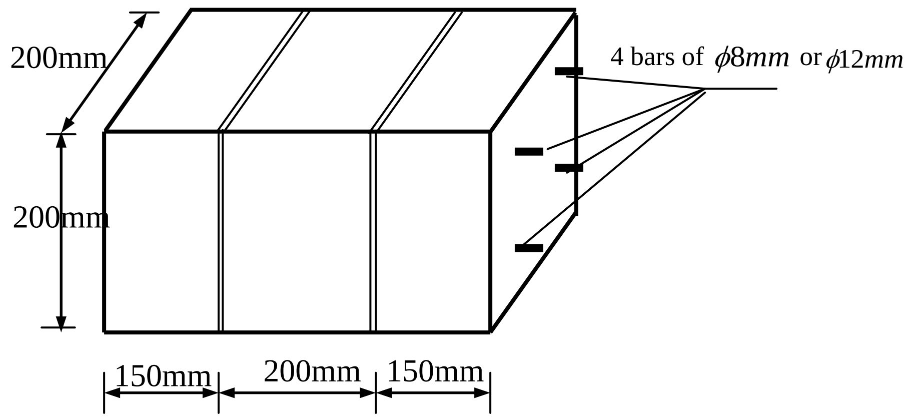

Fig.(1): Push – off test specimen

The middle prism is fabricated with a concrete having a cube compressive strength of 55 MPa (using rapid hardening cement) to simulate or represent the prestressed concrete, while the side prisms are made of concrete with cube compressive strength of 35 MPa for the representation of the slab concrete. The details of mix ratios are shown in Table (2) of Ref.(16). The middle prism is cast after fixing four deformed steel bars throughout the prisms length to represent dowels. The steel bars which are provided used as dowels are of the same bar diameter in each test. Four of the tests are with $\phi 8mm$ bars and other four tests with $\phi 12mm$ bars. After 24 hours, the mold of side parts are removed and replaced by a layer of polythene sheeting to represent the interface layer, then the side prisms are cast.

PHOTO (1) Middle prism and dowel bars used in the test

Table (2): Concrete mix designs (16)

Mix No.	Target strength (N/mm2)	Cement content (kg/m3)	Water content (kg/m3)	Fine aggregate content (kg/m3)	Coarse aggregate content (kg/m3)
1	35	300	180	701	1194
2	55	436	205	615	1094

The material properties are shown in Table (3). In 21 days of curing (14 days in water and in 7 days in air curing), the specimens were erected on a prepared frame fixed on a universal testing machine to conduct the test. Details of tests are shown in Fig. (2).

Table (3): Material properties used in the tests (16)

Concrete used	Cube compressive strength f_{cu} (N/mm2)	Tensile strength f_{ct} $f_{ct} = 2.8 + 0.02 f_{cu}$ (N/mm2)	Steel used			
			$\phi 12mm$		$\phi 8mm$	
			f_y (N/mm2)	E_s (N/mm2)	f_y (N/mm2)	E_s (N/mm2)
Middle prism	55	3.9	435	196000	485	196000
Edge prisms	35	3.5	---------	--------	-------	--------

The load was applied incrementally to the middle prism from the bottom to push it up while the side prisms were fixed and no movement was allowed for them. The corresponding slip was measured through two dial gauges. The record comprises shear load transferred through the interface and slip.

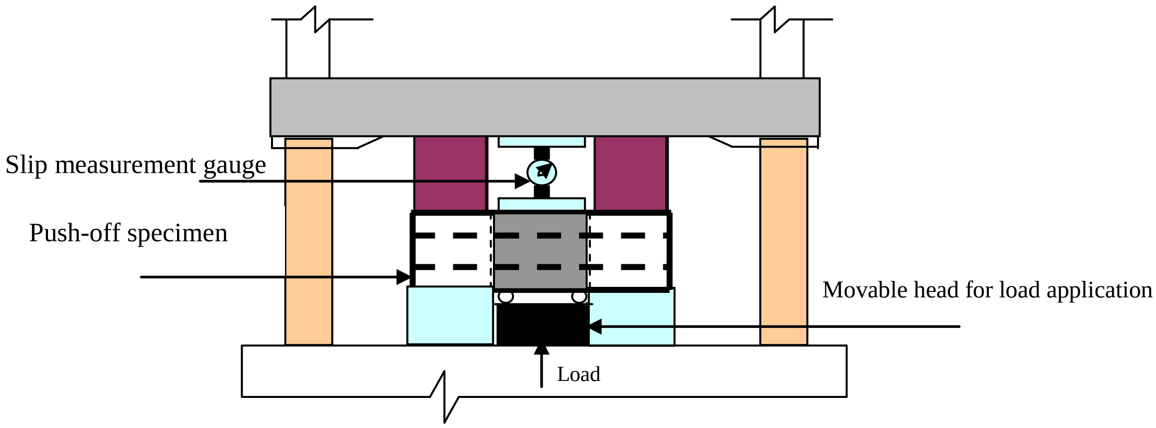

Fig.(2): Instrumentation and test of push-off specimens

RESULTS OF EXPERIMENTAL WORK

The results of the tests are shown in Table (4) for the dowel bars of $\phi 8mmm$ and for $\phi 12mm$ and compared with the results of Equation (2).

Figs. (3 and 4) show the relation between the shear force and the slip for two cases of dowel bar diameters selected $(\phi 8mm)$ and $(\phi 12mm)$.These relationships are represented in terms of shear force and slip for simplicity. It can be represented also by a relationship between the shear stress (which is mentioned also in Table (4)) and the slip. The shear stress, τ is defined as the total shear load transmitted by the reinforcement divided by the area of the crack. The area of the crack is represented by the area of the adjacent faces of the concrete prisms (200mmx200mm). It can be shown from the figures that increasing the diameter of the bars resulted in a higher shear stiffness and ultimate stress. Failure occurred not by splitting but by crushing of the concrete (Photos 2, 3, and 4). It is likely that the axial tension caused some localized damage and softening to the concrete so that there was a reduction in the splitting stresses below the bar at the crack (joint) face. The shear loading itself will also cause further damage to the concrete. This is likely to reduce the effectiveness of the tensile anchorage of the bar within the concrete and could explain why the crack became wider as shear loading was applied, Photo (4), even though no overriding of the crack faces was expected.

Table (4) Millard-Johnson Eq. (2) and experimental results

Dowel bar diameter (mm)	No. of bars		Shear force F_d (N)	0	4000	6000	8000	8800	9600	10400	10500	10600	10800	10836
8	4		Shear Stress τ (N / mm2)	0.00	0.10	0.15	0.20	0.22	0.24	0.26	0.2625	0.265	0.270	0.2709
		Δs (mm)	Millard & Johnson Eq.(2)	0.00	0.262	0.459	0.762	0.950	1.234	1.823	1.970	2.168	3.186	4.483
			Experimental	0.00	0.26	0.50	0.80	1.00	1.25	1.83	1.99	2.20	3.20	4.50
12	4		Shear force F_d (N)	0	16000	32000	48000	64000	72000	80000	84000	86000	88000	90000
			Shear Stress τ (N / mm2)	0.00	0.40	0.80	1.20	1.60	1.80	2.00	2.10	2.15	2.20	2.25
		Δs (mm)	Millard & Johnson Eq.(2)	0.00	0.113	0.254	0.437	0.704	0.901	1.198	1.430	1.593	1.817	2.179
			Experimental	0.00	0.11	0.26	0.45	0.80	1.00	1.30	1.45	1.65	1.85	2.25

Fig. (3) shows a comparison between the experimental and the analytical results governed by eq. (2) for bar of $\phi 8mm$ diameter (shear force transferred by dowel action with slip). At the same time the relationship between shear stress (transferred through interface by dowel action) and slip is explained in Fig. (5). The results give good comparison where most of the curve points coincided. In Figs. (4 and 6) the experimental and the analytical results of the tests using bar of $\phi 12mm$ diameter are shown. The results here give accurate coincidence with the others compared with the test of $\phi 8mm$ bars. This surely explains the truth that the shear stress transmitted by dowels is increased by increasing the area of dowel bars or the number of these dowel bars. The nonlinear shear stiffness of the dowel action specimens may be attributed to one or both of two causes. The first cause is splitting or crushing of the concrete supporting the bar and the second cause is the plastic yielding of the dowel bars.

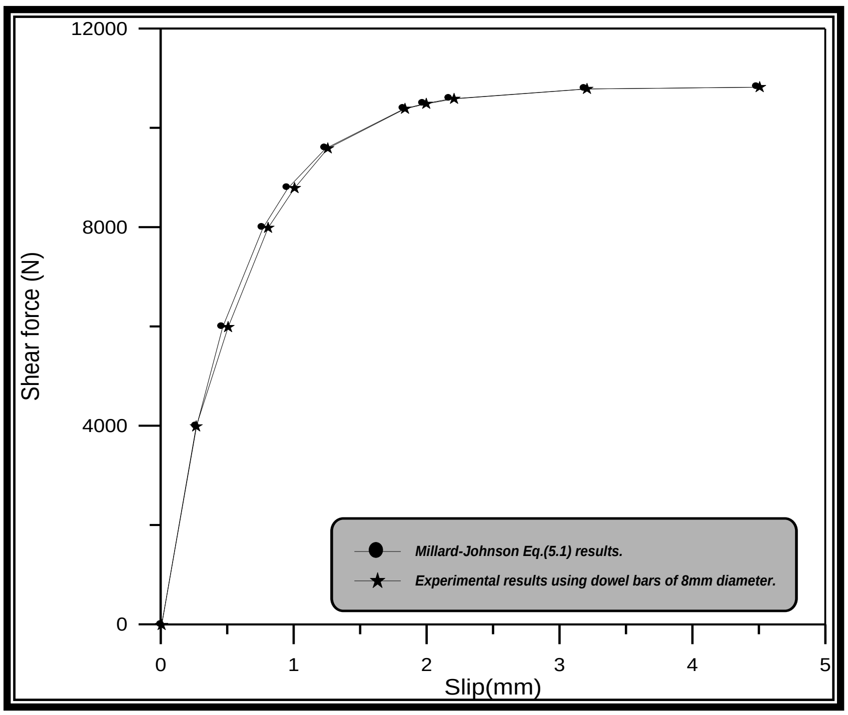

Fig.(3)Comparison between experimental and Millard-Johnson Equation (2) results using dowels of 8mm diameter bars

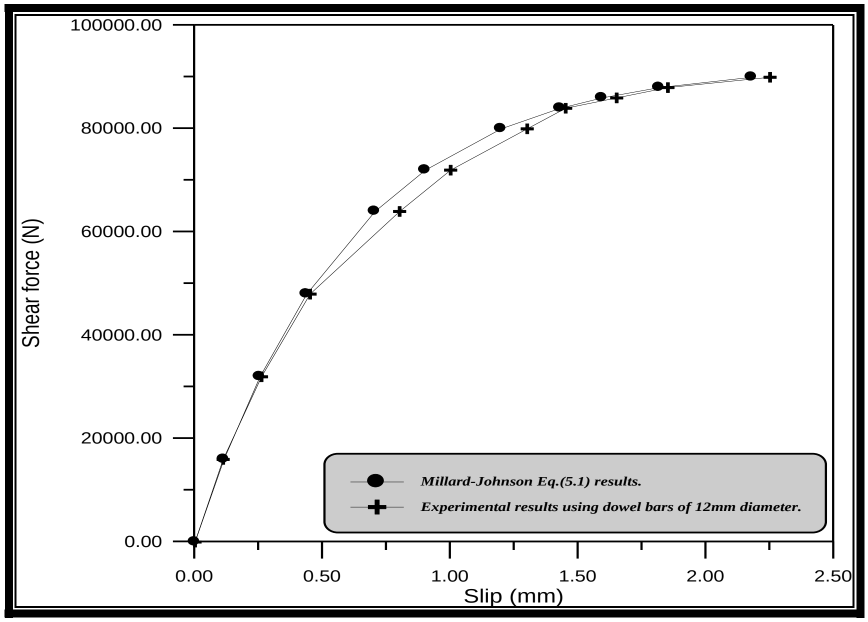

Fig.(4) Comparison between experimental and Millard-Johnson Equation(2) results using dowels of 12mm diameter bars

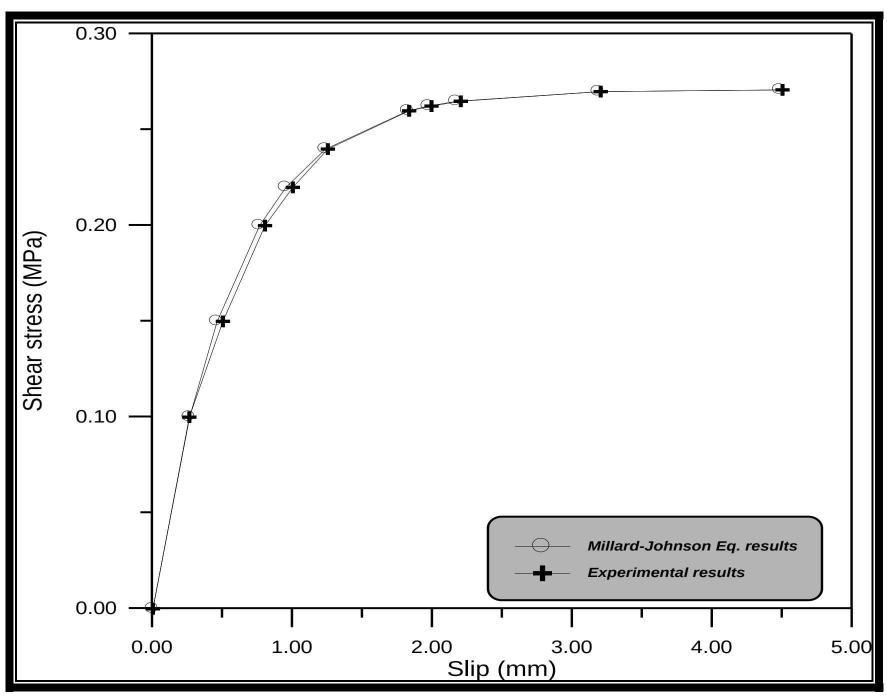

Fig.(5) Comparison between Millard-Johnson Equation results of shear stress-slip and experimental results using dowels of 8mm diameter

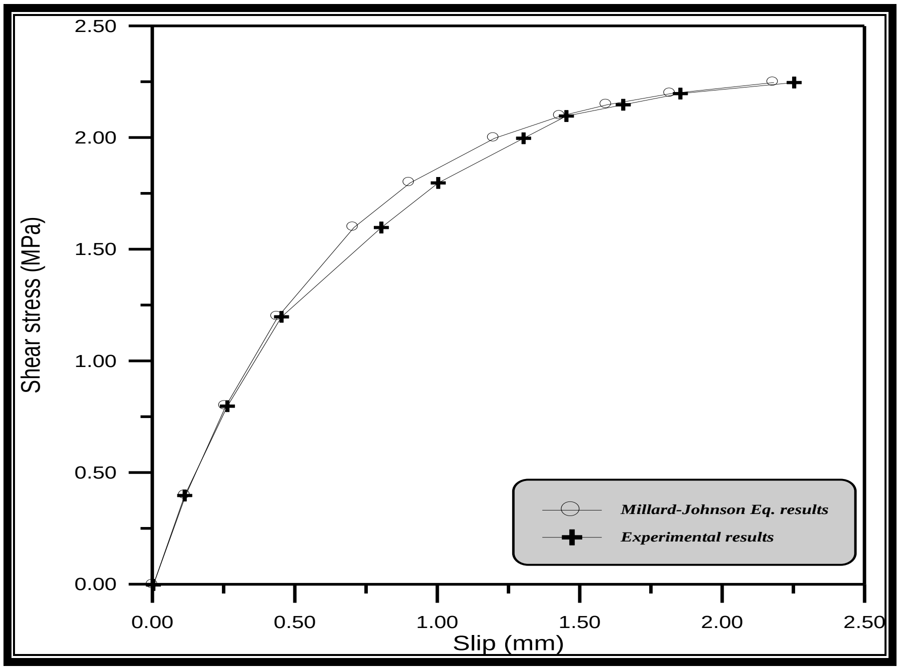

Fig.(6) Comparison between Millard-Johnson Equation results of shear stress-slip and experimental results using dowels of 12mm diameter

Photos (2, 3, and 4) show the failure mode of the specimens using dowel bars of 8mm diameter. It is clear from the pictures that the cracks are due to crushing of concrete near or under the dowel bars because of the reduction in splitting stresses under the bars. Photos (5, 6 and 7) are for dowel bars of 12 mm diameter. In these photos the same type of failure is repeated here with wider and more severe cracks.

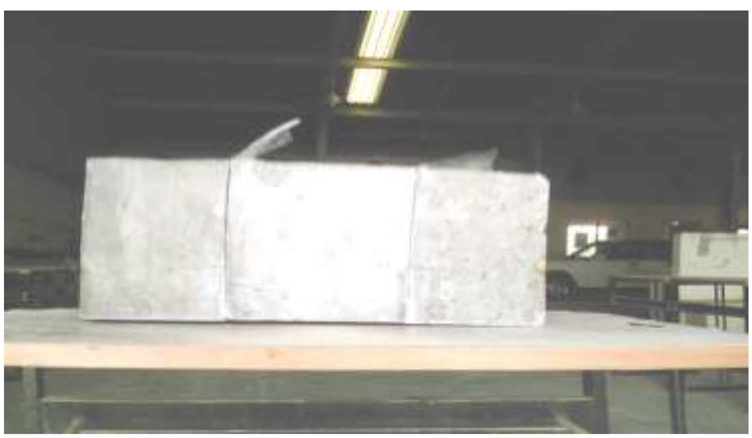

PHOTO (2) Specimen with 8mm dowel bars after test

PHOTO(3) Edge cracks with 8mm bars diameter specimens

PHOTO (4) Cracks in the face with 8mm bars specimens

PHOTO (5) Crushing failure of specimens with 12mm bars.

PHOTO (6) Face cracks with 12mmbars specimens

PHOTO (7) Upper and side cracks with 12 bars mm specimens

Finite element analysis of Hofbeck et al. reinforced concrete push-off specimens

The aim of the push-off tests which were done by Hofbeck et al. **(8)** was to study the transfer of shear across the interface between a precast prestressed girder and a cast -in – place slab. A typical specimen is shown in Fig. (7). Hofbeck et al. **(8)** tested thirty-eight specimens, some with and some without a pre-existing crack along the shear plane. 20-node brick elements of Al-Shaarbaf **(2)** for concrete with embedded bar elements were used in the present work. Also the interface was considered as a brick element with an existing crack or initially cracked. Details of dimensions and reinforcement of push-off test are shown in Fig. (7).

Material properties and the additional material parameters used in the finite element analysis are listed in Table (5)

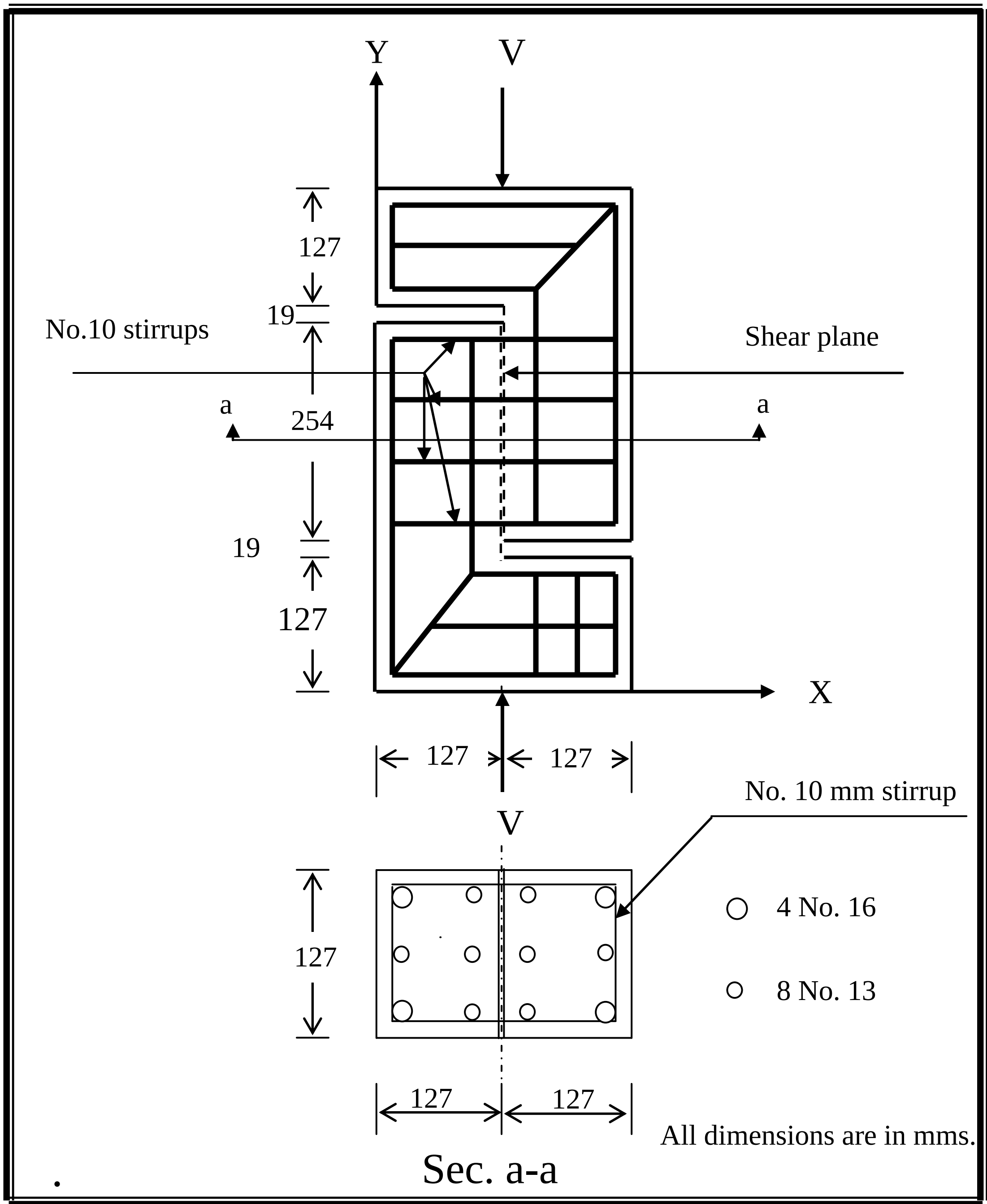

Fig.(7) Dimensions and reinforcement details of push-off specimen.

specimen

Concrete (interface also included)			
E_c	**Young's modulus (MPa)**		**25200**
f'_c **(Hofbeck et al. test) (8)**	**Compressive strength (MPa)**		**26.9**
f_t	**Tensile strength (MPa)**		**2.7**
ν *	**Poisson's ration**		**0.2**
Reinforcing steel			
E_s *	**Young's modulus (MPa)**		**200000**
f_y	**Yield stress (MPa)**	**No .10mm**	**349**
		No .13mm	**325**
		No .16mm	**292**
Tension stiffening parameters			
α_1	**Rate of stress release as the crack widens.**		**41**
α_2	**The sudden loss of stress at the instant of cracking.**		**0.6**
Shear retention parameters			
γ_1	**Rate of decay of shear stiffness as the crack widens.**		**10**
γ_2	**The sudden loss in shear stiffness at the instant of cracking.**		**0.9**
γ_3	**Residual shear stiffness due to the dowel action.**		**0.1**

(*) Assumed values

Finite element idealization of push-off specimen of Hofbeck et al.

The specimen which is considered by Hofbeck et al., as an initially cracked specimen is tested here. It is discretized into nine brick elements, one of them is the interface (element N0.5), Fig. (8).

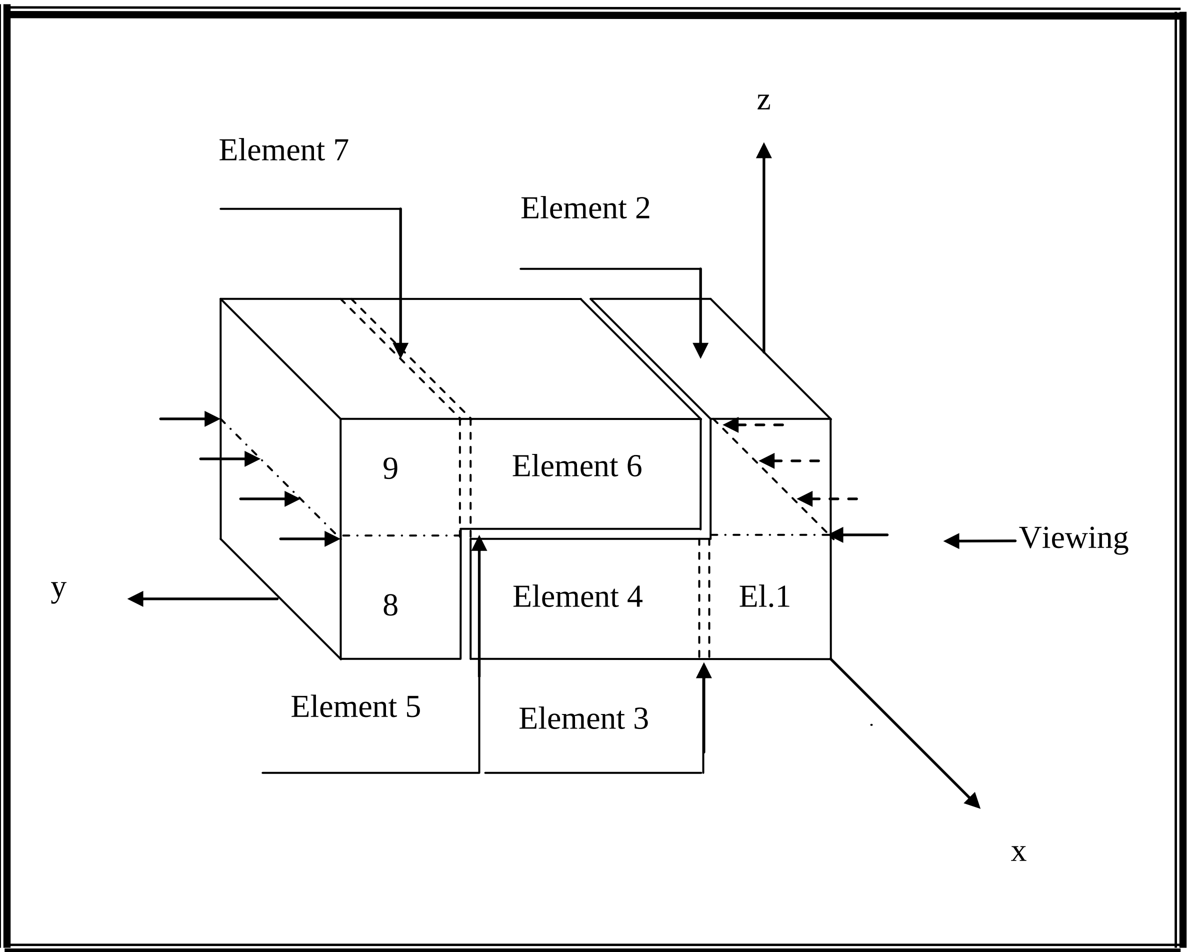

Fig .(8) Finite element mesh used for push-off specimen of Hofbeck et al in the present study

The interface element has a thickness of (0.01-0.1) b, where b is the length of the face adjacent to interface, Desai et al. **(5).** Therefore, depending on the previous assumption the thickness of the interface is taken to be 3mm (0.1b).

The distribution of the nodes in the 20 – noded brick elements is as shown in Fig. (9).

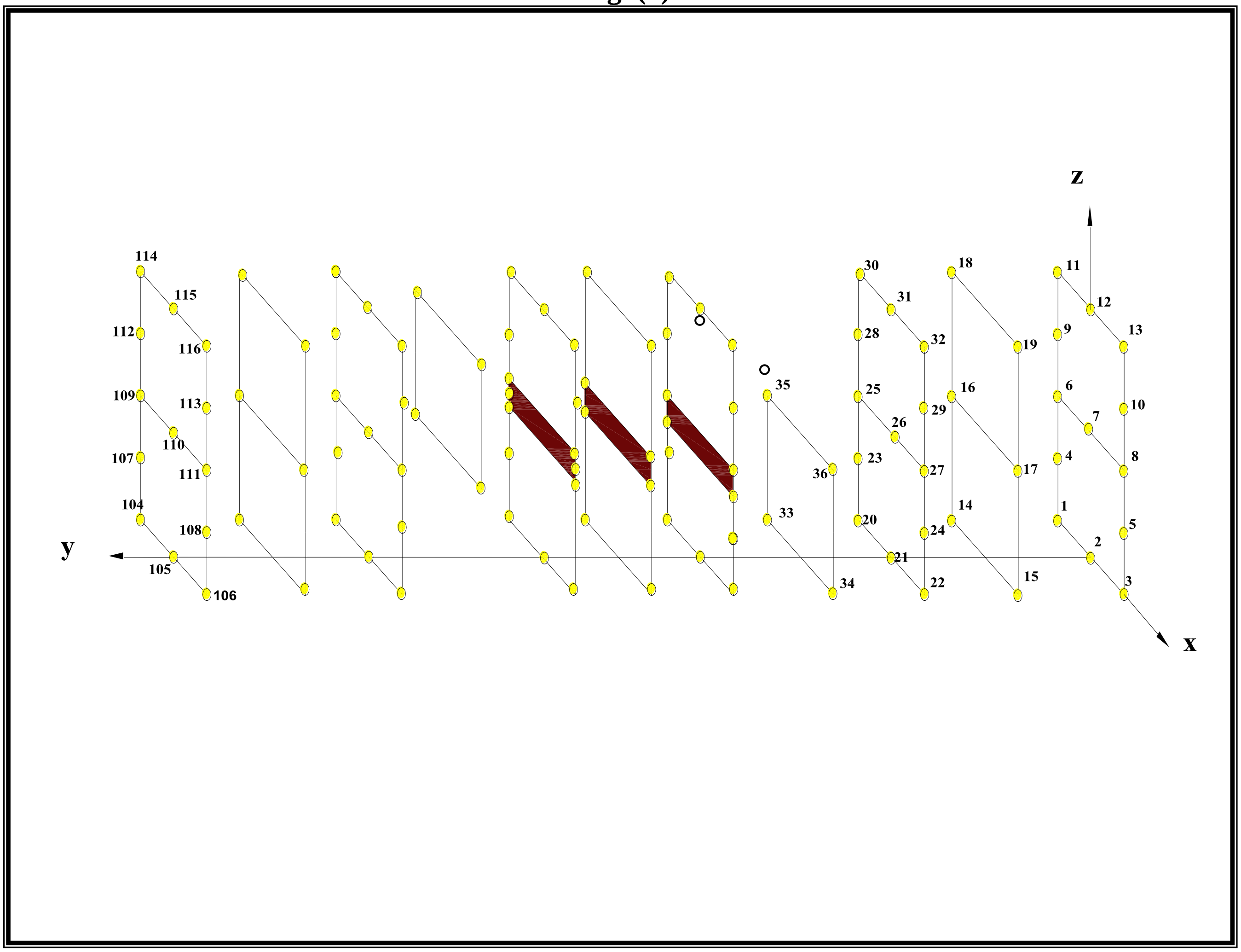

Fig. (9) Distribution of nodes on the 20- noded brick element of the test specimen

RESULTS OF THE ANALYSIS OF PUSH-OFF SPECIMEN.

In the analysis of push-off specimen tested by Hofbeck et al. **(9),** the interface model used is where dowels are used. The nonlinear Equation (11) of the shear modulus is added and contributed in the constitutive matrix $[D]$. The results of the analytical load-slip relation by finite elements are shown in Fig. (10) which are compared with the experimental results. The figure indicates good agreement throughout the entire range of load – slip behavior. The numerical ultimate load is (222.25 kN), while the experimental ultimate load is (222.3 kN).

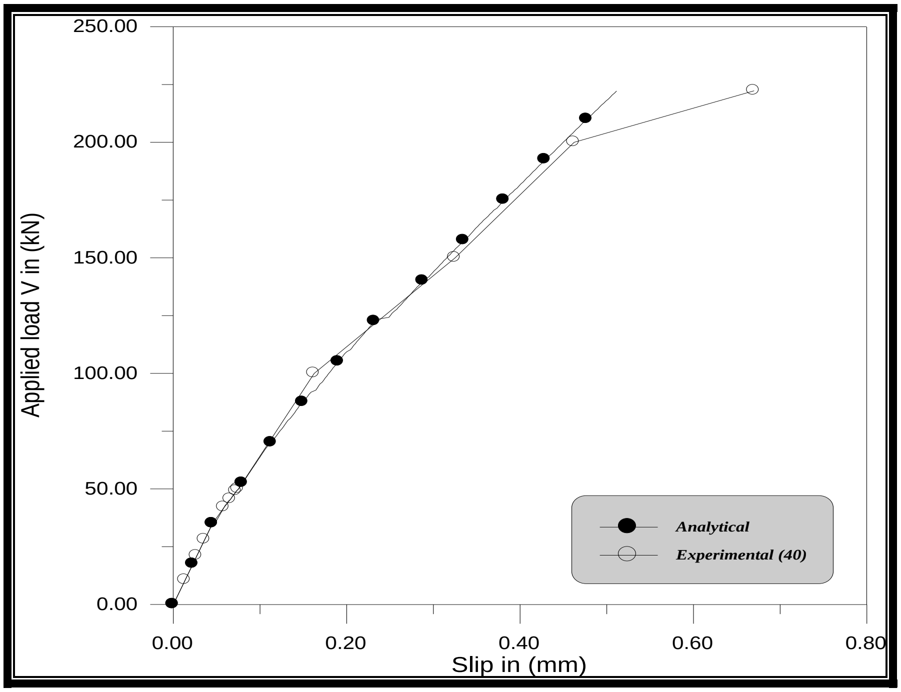

Fig. (10) Experimental and analytical load-slip curves of Hofbeck et al.(8) push-off specimen using Millard-Johnson nonlinear equation of dowel action

Fig. (11) shows the analytical results compared with the experimental results when the model of linear Equation (6), proposed by Millard and Johnson **(16),** is used. It is clear that there would be a difference larger than that shown in Fig. (10) when Millard-Johnson nonlinear equation is used, where the ultimate analytical load obtained is (224.875 kN).The ratio of the predicted load to the corresponding experimental load is (1.01158). Therefore it is preferable to use the Millard-Johnson nonlinear equation because the ultimate shear values in experimental and analytical results coincide. Besides it is well known that the relation between shear force transmitted through an interface and the slip is always of exponential form which coincides with that of Millard-Johnson equation.

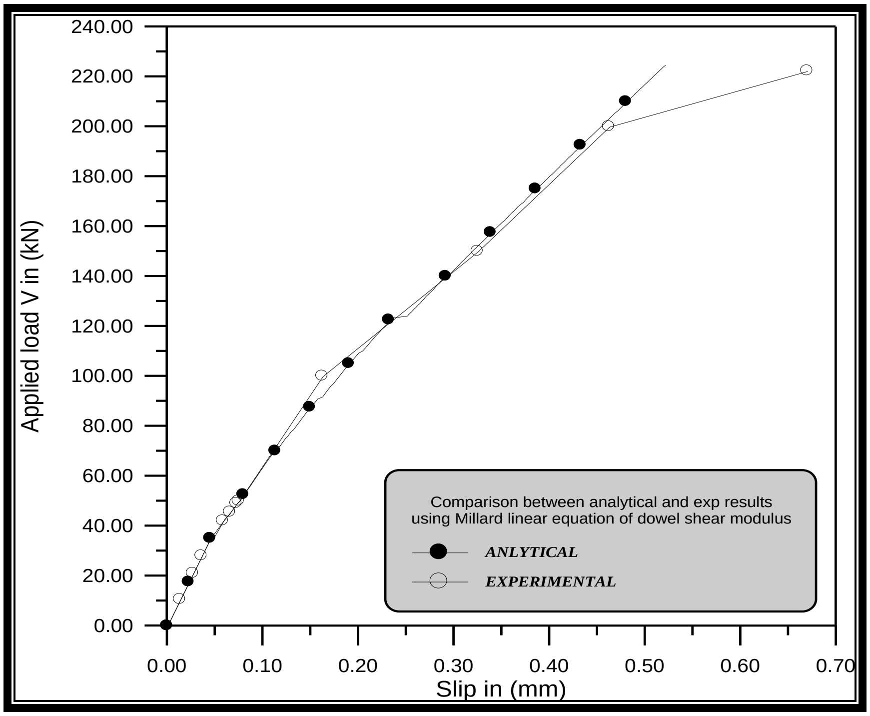

Fig. (11)Experimental and analytical load-slip curves of Hofbeck et al. for push-off specimen using Millard-Johnson linear equation of dowel shear modulus

CONCLUSIONS

The conclusions which can be deduced are listed herein:

1- The exponential equation presented by Millard-Johnson to represent the shear transfer through interface with slip by dowel action is sufficiently accurate. When comparing the results of this equation with the results of tests done in the present work and in Hofbeck et al. work, the two give good and reasonable comparison where the difference between analytical and experimental work is between 2.5% and 5% for 8mmϕ and 12mmϕ bars respectively.

2-The exponential equation is used only for initially cracked specimens because as crack initiates, the transfer of shear is achieved mostly by dowel bars and hardly by aggregate interlock.

3- As the area or number of dowels are increased the slip is decreased and that is due to the contribution of the bar stiffness in the overall stiffness of the member.

4-It is suggested to reach to a certain equation representing the shear transfer through interface by combined aggregate interlock and dowel action .

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