SHEAR CAPACITY OF CONCRETE PRISMS WITH INTERFACE JOINTS

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ABSTRACT:

Construction joints are frequently used in engineering structures for various reasons. When the size of the structure is relatively large stoppage of concrete casting at certain locations is necessary. Stoppage of casting may also occurs due to sudden failure of mixing machines, or when the concrete stock ingredients runs out of materials, or when weather conditions do not permit casting operations to continue. If stoppage of concreting occurs, a joint between old and new concrete forms, it is then necessary to evaluate the horizontal shear capacity at the interface between old and new concretes to prevent progressive slip from taking place and to insure satisfactory performance of the structure.

A total of 16 push-off tests were performed to quantify the shear strength capacity at the interface between old and new concretes and to recommend the necessary practice for such circumstances. Test parameters include different interface surfaces smooth and rough with and without shear keys. The variables also include presence of shear reinforcement across the interface surfaces.

Test results have indicated that leaving concrete surface at the end of casting rough with shear keys is essential to restore part of shear resistance between old and new concretes. Presence of shear reinforcement further improves the shear resistance at the interfaces. It was found that the average nominal shear capacity of concrete at the interface relative to the nominal shear capacity of control specimens cast monolithically is about 43% for rough surfaces having amplitude of 6mm and 55% for rough surfaces with shear keys. When 3-Φ10 shear reinforcement is used along rough interface, shear resistance increased to 62% relative to the shear capacity of control specimens cast monolithically.

مقاومة القص للمواشير الخرسانية التي تحوي على مفاصل إنشائية

الخلاصة:

تستخدم المفاصل الإنشائية في المنشآت لأسباب عديدة عندما يكون حجم المنشأ كبير نسبيا مما يتطلب توقف صب الخرسانة. إن توقف صب الخرسانة في المنشآت قد يحصل نتيجة العطل المفاجئ في أجهزة الخلط والصب أو عند نفاذ خزين المواد الإنشائية أو عندما تكون الظروف الجوية غير مناسبة لاستمرار عمليات صب الخرسانة. في مثل هذه الحالات يتولد مفصل إنشائي عند معاودة الصب. إن وجود مفصل إنشائي يتطلب احتساب قوى القص الأفقية التي تتولد على سطح الخرسانة المصبوبة قبل توقف الصب والخرسانة الجديدة لاتخاذ الإجراءات المناسبة لمنع الحركة الأفقية بين سطحي الخرسانة ولضمان أداء جيد للمنشآت.

تم في هذا البحث فحص 16 موشور خرساني لتقييم مقاومة القص بين سطوح الخرسانة المصبوبة في أوقات مختلفة. وتضمن البرنامج العلمي الاخذ بنظر الاعتبار متغيرات نعومة وخشونة السطوح مع وجود جيوب القص. كما وتضمنت المتغيرات وجود حديد التسليح على هذه السطوح.

أظهرت النتائج بأنه عندما تكون السطوح الخرسانية المصبوبة خشنة مع وجود جيوب القص فأن جزء من مقدار مقاومة القص يمكن استرجاعها كما وان استخدام حديد التسليح على سطحي الخرسانة يؤدي إلى تحسين مقاومة القص بين هذه السطوح. وقد وجد

بان استخدام أوجه خشنة مع جيوب القص يؤدي إلى الحصول على مقاومة قص تبلغ 57% من مقاومة القص للمواشير المصبوبة بدون مفاصل إنشائية وبإضافة حديد تسليح قطر 10 ملم وبعدد 3 فان مقاومة القص تزداد إلى 65%.

KEYWORDS: shear, capacity, concrete, prism, interface joints, rough, smooth, surface

INTRODUCTION:

The basic requirement at joints or at interface between new and old concretes is that all forces existing at the interface must be transmitted in the same manner. To accomplish such condition, it is essential to rely upon the surface condition at the interface and/or to place reinforcing bars across the interfaces (1, 3, and 4). In composite construction, failure may precipitate in the vicinity of the connection as a result of high shear stresses which may develop at the interface of pre-cast (old concrete) and cast-in-situ concrete (new concrete). If the interface surface is not well roughened or reinforcement is not provided failure may occur.

According to ACI code (1), shear transfer across a given plane such as an existing or potential crack; an interface between dissimilar materials or an interface between two concretes cast at different times; shear friction reinforcement is intended to transfer shear across an interface between concretes cast at different times.

Concrete is relatively strong in direct shear but it is possible that crack will form in unfavorable manner. Shear friction reinforcement is provided across the crack to resist relative slip between two surfaces of concrete cast at different times (1, 3, and 4). If the crack faces are rough and irregular, the slip is accompanied by separation of the crack faces. At ultimate, the separation is sufficient to stress the reinforcement crossing the crack to its yield point (3, 4). The reinforcement provides a clamping force across the crack faces. The applied shear is resisted by friction between the crack faces; by shearing off protrusions on the crack faces; and by dowel action of the reinforcement crossing the crack.

Fatmir Menkulasi (2) in his study on horizontal shear connectors for precast prestressed bridge deck panels indicated that in typical push-off tests, the specimens reach their maximum load immediately before the bond was broken. For specimens with no shear connectors, some small shear capacity is maintained, while specimens with shear connectors once the bond broken the load reduced and maintained for large slips at a value equal to the yield capacity of the connectors times some factor.

The author also indicated that the equations available in ACI code are unconservative for precast panel system and give high shear stresses at the interface relative to the obtained test results.

Joseph A. Wallenfelsz (5) tested 29 push off tests to quantify peak and post-peak shear stresses at the interface at failure. The variables of study include surface treatment of the surface of the specimens, type and amount of shear connectors and presence of pocket shear keys. He indicated that when headed shear connectors is used an exposed aggregate surface treatment is not required. He also concluded that specimens with headed shear connectors behave in similar manner to stirrup shear connectors.

In this paper, an attempt have been made to quantify interface shear capacity of concrete prisms cast at different times with various combinations of smooth and rough surfaces with and without shear reinforcement along the interface.

ACI CODE PROVISIONS FOR SHEAR FRICTION REINFORCEMENT:

ACI- 318M-08 (1) approach for shear transfer a cross a given plane is based on calculating the nominal shear strength using the following equation:

$$\mathbf{V_n = A_{vf} f_y \mu} \quad \text{(kN)} \qquad (2.1)$$

Where:
Vn = nominal shear strength
Avf = area of shear friction reinforcement
fy = specified yield strength of shear friction reinforcement
μ = coefficient of friction

The coefficient of friction μ shall assume a value which ranges between 1.4λ for concrete placed monolithically to 0.6λ for concrete placed against hardened concrete not intentionally roughened, where λ is a modification factor reflecting the reduced mechanical properties of lightweight concrete of the same compressive strength. λ =1.0 for normal strength concrete and equal to 0.75 for all lightweight concretes.
The ACI code also specify that for normal weight concrete placed monolithically or placed against hardened concrete with surface is intentionally roughened, the factored shear strength shall not exceeds the smallest of :

$$\mathbf{V_n = 0.2f'_c A_c} \tag{2.2}$$

$$\mathbf{V_n = (3.3 + 0.08f'_c)A_c} \quad \text{(kN)} \tag{2.3}$$

$$\mathbf{V_n = 11A_c} \tag{2.4}$$

Where Ac is the area of concrete section resisting shear transfer, and fc' is the lower strength of the concretes used. The code also specifies that when concrete is placed against previously hardened concrete, the interface for shear transfer shall be clean and free from laitance. If in the calculation μ is assumed equal to 1.0λ, the interface shall be roughened to full amplitude of approximately 6mm.

EXPERIMENTAL WORK:
To examine the horizontal shear transfer capacity at the interface surfaces, 16 push off tests were conducted. The variables include surface conditions (smooth or rough), presence of shear keys, and presence of shear reinforcement between the interfaces.

Push-off Tests:
Push off tests which were used to investigate shear resistance at the interface between new and old concrete is shown in Fig. 1. From this test an evaluation of the average nominal shear capacity at the interface of old and new concretes as well as the contribution of steel shear connectors to the interface shear strength can be made. Various combinations of surface treatment with and without steel reinforcement were employed for this purpose.

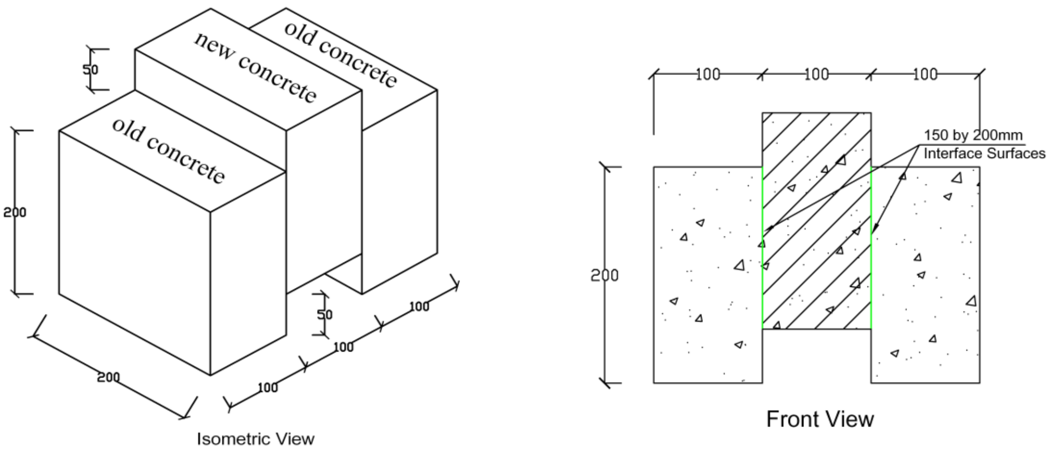


Fig. 1: Isometric and Front Views of the Tested Specimens

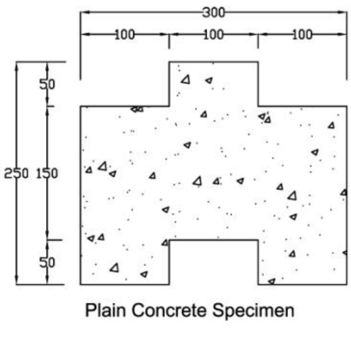
Plywood moulds were prefabricated to cast the specimens. It consists of three 100X100X200mm size prisms separated by thin plywood sheets. The edge prisms were cast first, while the middle prism was cast the next day. Surface treatments of the interface were done on the edge prisms, before casting the middle prism. Steel reinforcement across the interface was embedded in the edge prisms and was concreted the next day during casting the middle prism.

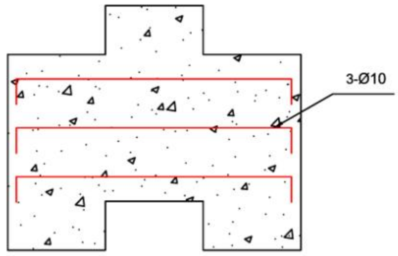
The concrete used were produced using mix proportions of 1:2:3 cement, sand, and aggregate by weight, and a w/c ratio of 0.5. The average strength of concrete calculated based on testing 150mm cubes at age of 28 days is 30 MPa (24 MPa cylinder strength).

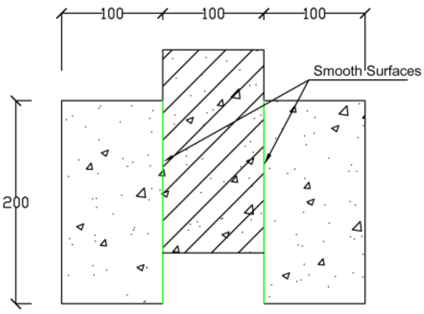
Specimen Classification and Testing Procedure:

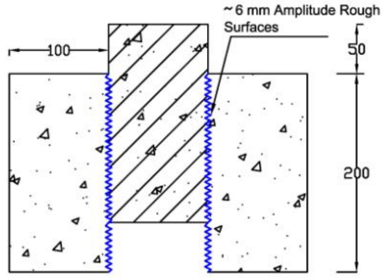
16 specimens were cast; four specimens of them were used as control specimens for no joint unreinforced specimens and no joint reinforced specimens across the interface. The rest of the specimens were divided into six groups, each group consists of two specimens for the variables investigated at the interface as shown in Table 1 below. 3-Φ10 mm reinforcing bars were used at the interface between old and new concretes which provide a shear reinforcement ratio ρv = 0.785%. The vertical spacing between these bars is 50 mm c/c. they were placed at the edge prisms extending to the end of the middle prism. The yield strength of the reinforcement used is 410 MPa.

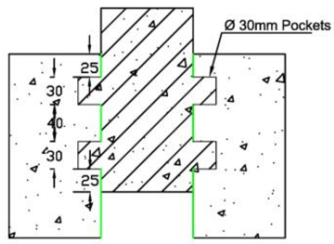
Table 1: Specimen Classifications and Details.

Specimens Designation	No. of Specimens	Shape
Control specimen, no joints, no shear reinforcement	2	

<table>
<tr><th>Specimens Designation</th><th>No. of Specimens</th><th>Shape</th></tr>
<tr><td>Control specimen, no joints, with 3-Ø10 shear reinforcement</td><td>2</td><td>


Reinforced Concrete Specimen
</td></tr>
<tr><td>Smooth surfaces, no shear reinforcement</td><td>2</td><td>


Specimen with Smooth Surfaces
</td></tr>
<tr><td>Intentionally roughened surfaces to 6mm amplitude, no shear reinforcement</td><td>2</td><td>


Reinforced Specimen with Rough Surfaces
</td></tr>
<tr><td>Shear key specimens with smooth surfaces,</td><td>2</td><td>


Shear Key Specimen with Smooth Surfaces
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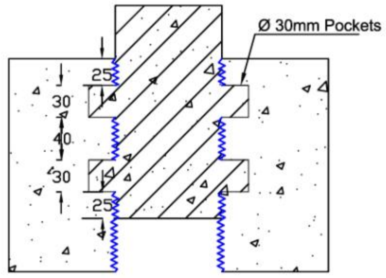
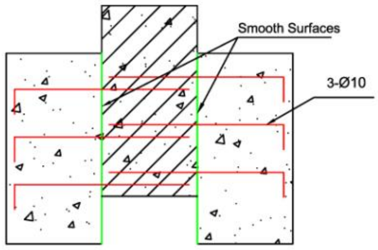
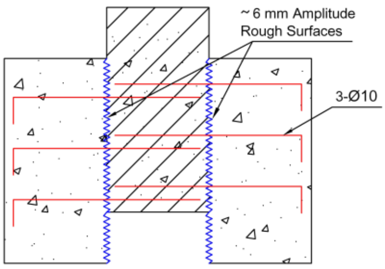
</table>

Specimens Designation	No. of Specimens	Shape
Shear key specimens with intentionally roughened surfaces to 6mm amplitude	2	 Shear Key Specimen with Rough Surfaces
Smooth surfaces with shear reinforcement	2	 Reinforced Specimen with Smooth Surfaces
Intentionally roughened surfaces to 6mm amplitude, with shear reinforcement	2	 Specimen with Rough Surfaces

The specimens were tested using 2000 kN ELE compression testing machine. The tested specimen was placed concentrically within the platens of the test equipment and the load is applied continuously at a loading rate of 1 kN/sec until failure occurs. The time of test was about 4 to 8 minutes. Before testing, a dial gauge with sensitivity of 0.01mm was used to measure the displacement (slip) of the middle prism. An angle shaped plate, glued with epoxy resin to the front face of the middle prism, is used to support the dial gage movable lever. The top and bottom surfaces of the specimen were capped using thin layers of gypsum plaster. Test setup and instrumentation are shown in Figs. 2 and 3.

Fig. 2: Specimen Inside the ELE 2000 kN Testing Machine.

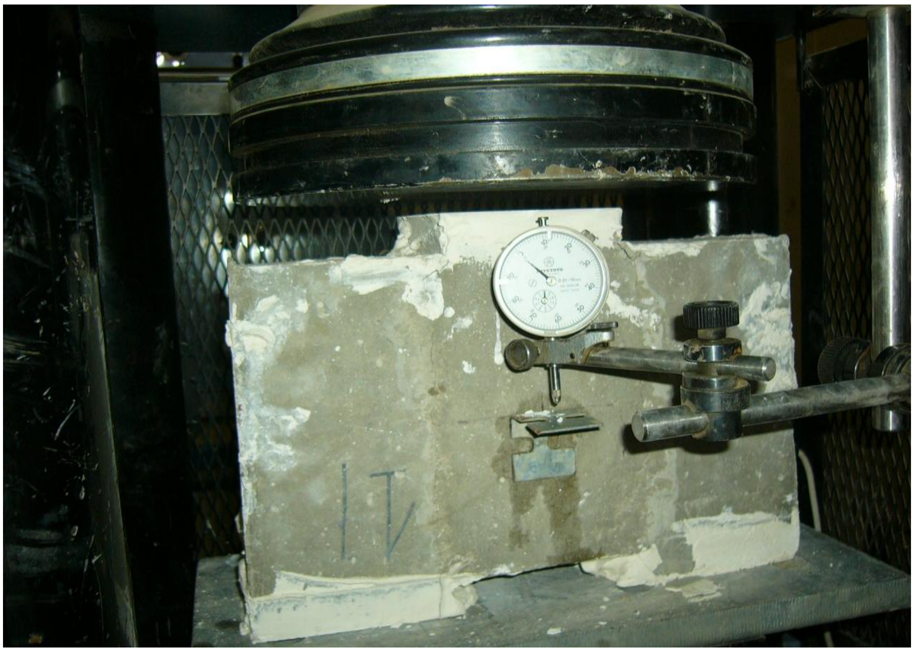


Fig. 3: Dial Gauge Location to Measure Slip of the Middle Part of the Specimen.

During tests, the tested specimens were visually inspected for cracks along the interfaces. It was observed that the specimens continue to carry load without distress until near failure where a crack along the interfaces appeared at which the specimen can not carry further load and the test is terminated. Figs. 4, 5 and 6, show typical failure pattern of reinforced specimens. Typical failure surfaces of specimens with and without shear keys are shown in Figs. 7 and 8.

Fig. 4: Failure of Control Specimen with Shear Reinforcement.

Fig. 5: Failure of Reinforced Specimen with Smooth Interface Surfaces.

Fig. 6: Failure of Reinforced Specimen with Roughened Interface Surfaces to 6mm Amplitude.

Fig. 7: Failure Surfaces of Specimen with Two 30mm Shear Key Discs.

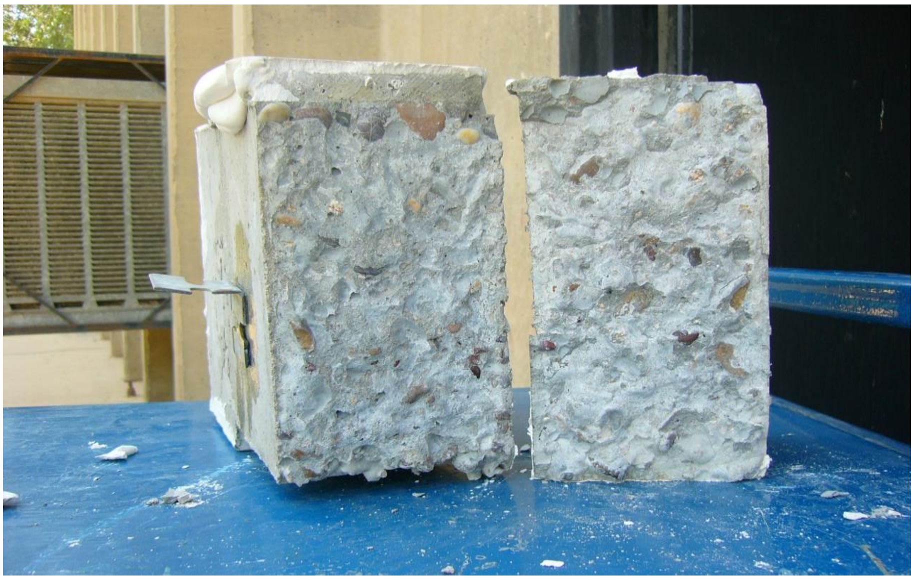


Fig. 8: Failure Surfaces of Specimen with Roughened Interface Surfaces to 6mm Amplitude.

The average capacity of unreinforced control specimens without joints is 235 kN; while the strength of control reinforced specimens reinforced across the interface is 404 kN. One specimen with smooth joints failed during handling while the other failed at a very small load. Specimens with interface surfaces which were intentionally roughened to full amplitude of about 6mm shows an average strength before failure of about 101 kN. When shear key type shear connectors is used in the form of 30mm diameter disks the average shear capacity is increased by about 28% relative to the intentionally roughened surface specimens, regardless whether the interface surfaces are left smooth or intentionally roughened. Test results are presented in Table 2 below.

Table 2: Interface Shear Transfer Capacity of the Tested Specimens

Specimen Designation	V_n (kN)	V_n (kN) Average	$V_{capacity} / V_{control}$
Unreinforced 1 (control)	290	225	control
Unreinforced 2 (control)	160		
Smooth 1	40	20	0.085
Smooth 2	0		
Rough 1	85	101	0.43
Rough 2	117		
Shear key Smooth 1	110	123	0.52
Shear key Smooth 2	136		
Shear key Rough 1	114	129	0.55
Shear key Rough 2	144		
Rein. 1 (control)	464	404	control
Rein. 2 (control)	344		
Smooth Rein. 1	72	82	0.20
Smooth Rein. 2	92		
Rough Rein. 1	142	145	0.36
Rough Rein. 2	148		

The effect of surface type (smooth or rough) becomes apparent when the interface is crossed by shear reinforcement along the interface between old and new concretes. Test results indicate that the average shear capacity of reinforced specimens with smooth joint surfaces is 82 kN while the average shear capacity of reinforced specimens with roughened joints is 145kN.

The results also indicate that the shear capacity of reinforced specimens with rough interface surfaces is about 62% of the capacity of unreinforced control specimens. This mean that the shear capacity of the interface can better be restored if the interface surfaces are roughened to 6 mm amplitude supplemented with shear reinforcement.

- LOAD-SLIP RELATIONSHIP:

Typical load–slip plots for unreinforced and reinforced control specimens are shown in Fig.9. For unreinforced control specimen three stages of behavior can be recognized. In the first stage, the slope of the load- slip curve is small as compared to the slope of the second stage which shows stiffer response until near failure when the slope drops to zero indicating a crack has formed along the interface between the middle and the edge parts of the of the specimen.

The slope of the three stages of the reinforced specimen is higher than those of unreinforced specimen associated with smaller slip for the same load level. The presence of reinforcement increased the capacity of the specimen from 290 kN to 464 kN. The slip at failure is about 0.4mm for unreinforced specimen and about 0.58mm for reinforced specimen.

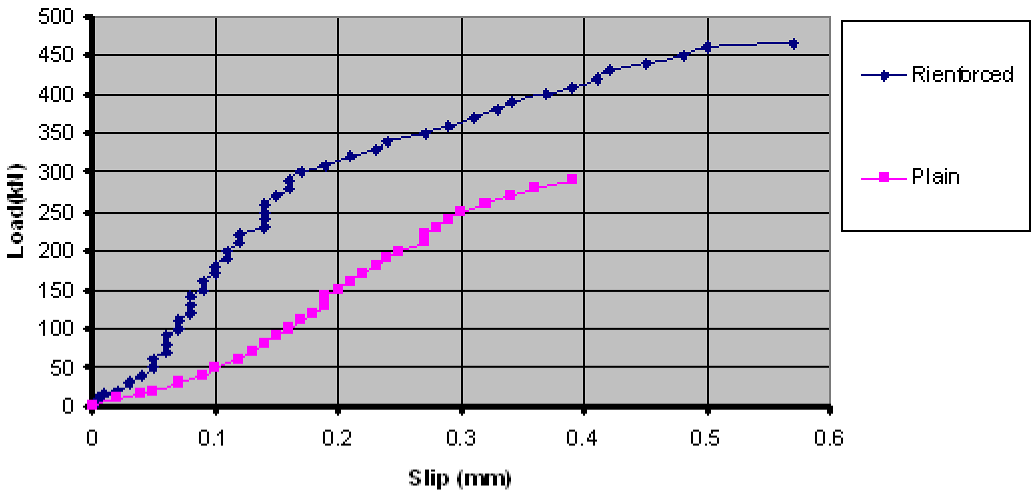


Fig. 9 : Typical Load-Slip Relationship for Control Specimens.

Typical load slip relationships for reinforced specimens with rough or smooth interface surfaces (joints) are shown in Fig.10. The curves show that the presence of joints has resulted in decrease in capacity relative to reinforced specimen. Specimen with smooth surfaces suffers more reduction in capacity than specimens with rough surfaces. The average capacity of smooth and rough surface specimens is 20% and 36% relative to the capacity of reinforced control specimen. The slip at failure is about 0.18mm for reinforced specimens with interfaces and about 0.58mm for reinforced control specimen without interfaces.

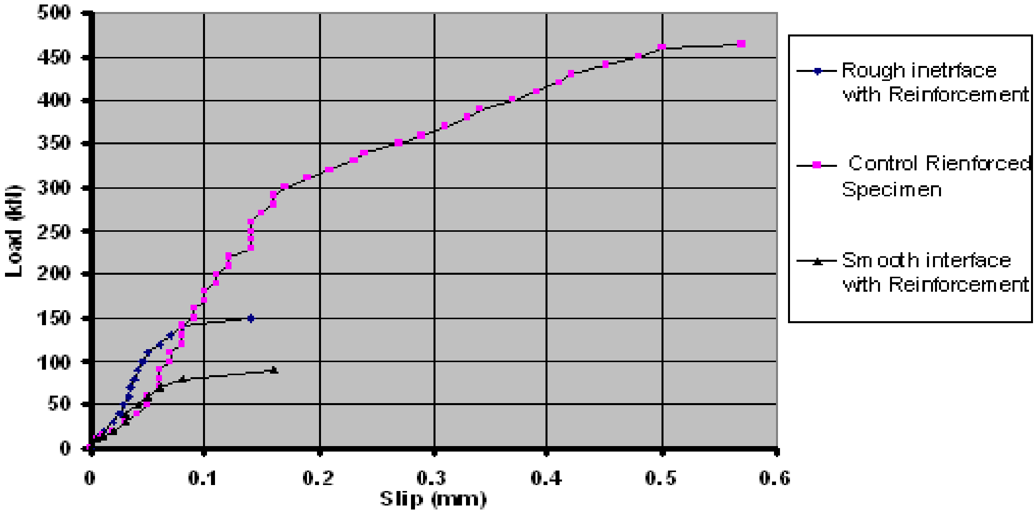


Fig. 10 : Typical Load-Slip Relationship for Reinforced Specimens.

- DISCUSSION OF RESULTS:

Control reinforced specimens with 3-Ø10 shear reinforcement (placed at the same locations of the reinforcement used to reinforce prisms with shear interfaces) and cast monolithically (without joints) shows an average capacity of 404 kN, while unreinforced control specimens shows an average capacity of 225 kN. If the shear resistance contribution of concrete at the location of the interfaces is assumed 225 kN, then the extra shear resistance of 179 kN can be thought of as the contribution of the reinforcement crossing the interfaces on both sides of the specimen. Based on the above, the stress in the reinforcement is about 380 MPa which means that at failure the reinforcement has not yielded.

According to ACI code limitations, the nominal shear contribution of concrete Vn should be the lesser of eqs. (2.2), (2.3) or (2.4) presented earlier, which according to specimen size and details are 288 kN. This is 63 kN greater than the nominal shear capacity of concrete obtained in this investigation. The ACI code equations seem to overestimate shear concrete contribution at the interfaces. Fatmir Menkulasi (2) also reported that the ACI equations are unconservative for precast panel systems and give high shear stress capacity relative to test results.

Reinforced specimens with shear interfaces were found to develop much less shear capacity as compared to reinforced control specimens without joints. The percentage reduction relative to reinforced control specimens is about 20% and 36% for smooth and rough surfaces respectively. This reduction in capacity may be discussed in terms of the shear resistance of concrete at the interface and the length of embedment of the reinforcement as follows:

The average shear capacity of roughened concrete surface specimens was found to be 101 kN, while the shear capacity of similar specimens with shear reinforcement is 145 kN as shown in Table 3. This means that the shear reinforcement contribution is only 44 kN (i.e. the reinforcement has not yielded). Comparison between capacity of control specimens and specimens with rough interface surfaces indicates that there is a decrease in concrete transfer capacity from 225 kN (for unreinforced no joint control specimens) to 101 kN (for specimens with rough interface surfaces), and a decrease in reinforcement contribution from 179 kN (for reinforced no joint control specimens) to 44 kN (for reinforced specimen with roughened interface joints) as shown in Table 3.

If such an analysis is accepted, it means that when an interface is necessary, concrete can furnish about 45% of the shear strength of specimen without joints or interfaces (i.e. 101 kN), and the addition of shear reinforcement should compensate for the remaining 55 % of capacity (i.e. 225kN - 101kN=124kN). It is believed that the contribution of reinforcement can be increased if the shear reinforcement used is well anchored within the new concrete (middle prism of this investigation) using 90 degree hooks or the length of reinforcement embedment is increased so that the full yield strength of the reinforcement can be utilized. In addition the capacity can also be restored if the shear reinforcement ratio ρv is increased so that the shear capacity of specimens with interfaces approaches the shear capacity of control unreinforced specimens.

Table 3: Contribution of Concrete and Reinforcement to Shear Transfer Capacity

Specimen type	Shear capacity(kN)	Contribution of concrete (kN)	Contribution of reinforcement (kN)
control Unreinforced	235	235	-------------------
control reinforced	404	235	169
Rough no reinforcement	101	101	--------------------
Rough with reinforcement	145	101	44

CONCLUSIONS:

Based on the experimental results presented, the following conclusions are drawn:

* At places where concrete casting is stopped, the surface of concrete should be left rough to at least 6mm amplitude to improve concrete shear strength contribution. It was found that rough concrete interfaces develop about 45% of the shear capacity of control specimens cast monolithically.

* Shear keys were found to improve concrete shear capacity at the interfaces between old and new concrete faces. It was found that specimens with rough interfaces and shear keys develop about 55% of the shear capacity of control specimens.

* Use of shear reinforcement across the interfaces enhances the shear resistance at the interface of old and new concretes. It was found that the shear capacity at the interfaces increased from 101 kN for specimens with rough surfaces to 145 kN for similar specimens with shear reinforcement ratio $\rho v = 0.785\%$.

* When shear reinforcement is used, it is necessary to insure enough embedment length within the opposite interfaces of old and new concretes so that the yield strength of the reinforcement can be developed.

* It is necessary to validate the ACI code equations for shear capacity of concrete between the interfaces of old and new concretes. It was found that the shear resistance capacity of concrete specimens of this investigation at the interfaces calculated based on ACI code eqs. (2.2), (2.3) or (2.4) presented earlier is 288 kN while test results of control specimens of this investigation (without joints) develop an average concrete shear capacity along the interfaces of 225 kN.

RECOMMENDATIONS:

The following recommendations were based on the results of this investigation:

- It is necessary to further investigate the interface shear capacity of concrete cast at different times to validate the ACI code equations.
- It is necessary to investigate the effect of using higher shear reinforcement ratios on shear capacity at the interfaces of old and new concretes.

- It is necessary to investigate the effect of presence of 90 degree hooks and embedment length of reinforcement on shear resistance capacity at the interfaces.

REFERENCES:

- ACI Committee 318;"Building Code Requirements for Structural Concrete (ACI 318M-08) and Commentary," American Concrete Institute, Farmington Hills, 2008, 473pp.

- Fatmir Menkulasi, "Horizontal Shear Connectors for Precast Prestressed Bridge Deck Panels," Thesis submitted to Faculty of Virginia Polytechnic institute, Blacksburg, Virginia, August 2002.

- MacGregor, J. G., Reinforced Concrete, Mechanic and Design, 3rd ed., Prentice Hall, Upper Saddle River, New Jersey, 1997.

- Nilson, A. H.; Darwin D.; and Dolan, C. W., Design of Concrete Structures, 13th ed. McGraw Hill, 2003.

- Wallenfelsz, J.A., "Horizontal shear transfer for Full-Depth Precast Bridge Deck Panels, " Thesis submitted to Faculty of Virginia Polytechnic institute, Blacksburg, Virginia, 25th February 2006.