- Technical Paper -

PERFORMANCE OF PRECAST CONCRETE JOINTS IN CYCLIC SHEAR BY USING PREPACKED CONCRETE

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ABSTRACT

Prepacked concrete assures aggregate contact or interlocking in reinforced concrete construction. The performance of prepacked concrete in smooth joint interfaces subjected to cyclic shear is investigated. Specimens with different aggregate distributions within the mortar mix are considered. The specimens are loaded with a cyclic shear of less than static dowel capacity, and progressive concrete deterioration initiated from the joint interface is detected. This deterioration has shown to depend on the kind of composite on coarse aggregates of normal and prepacked ones.

Keywords: dowel action, joint interface, prepacked concrete, splitting crack, aggregate distribution

1. INTRODUCTION

Shear transfer across jointed precast members is mainly attributed to dowel action. This mechanism is also considered for pavements, repaired structures, and cracked reinforced concrete structures (within ultimate limit states). In the general shear design of RC, the shear capacity without lateral reinforcement is hardly ever considered. The dowel action by longitudinal bars may contribute to the effective utilization of shear transfer across jointed interfaces. Dowel action for RC assures failure to be ductile given all the assumptions are held valid.

The critical dowel load or the bending resistance of dowel bars depends on the diameter, strength of the bars, and the strength of the concrete. Simple dowel capacity assessments are proposed in several types of research. The equations below present the ultimate and design capacity of dowel action [1].

$$D_u = 1.3\, D^2 \sqrt{f_{ck} f_{yk}} \quad (1)$$

$$D_{u,d} = D^2 \sqrt{f_{ck} f_{yk}} \quad (2)$$

where,

- D_u : critical dowel capacity
- D_{ud} : design dowel capacity
- D : reinforcement bar diameter
- f_{ck} : characteristic compressive strength of concrete
- f_{yk} : characteristics yield strength of reinforcement bar

Under cyclic loading conditions, degradation of dowel capacity has been considered by many researchers [1], [2], [4], and this is caused mainly by local bearing fracture of concrete. In normal use, joints subjected to loads less than the static critical loads are expected to be within the elastic range and no concrete or reinforcing bar's strength degradation is expected to occur within this range. This beam on the elastic foundation principle has been the basis to determine local strains and stresses.

In this research, less action than the critical dowel capacity was repeatedly applied to dowel joint planes, and the degradation of concrete under the different aggregate arrangement is studied using prepacked concrete where bearing compression beneath the dowel bars may be transferred through the direct contact of coarse aggregates.

2. TEST PROGRAMS

2.1 Specimen Design

In the past, experiments of different setups have been used to evaluate joint capacities under shear. These setups can be roughly categorized depending on load application methods. Loads are applied directly to the dowel bars or the jointed concrete unit [2],[4]. In some research, to determine the effect of the interaction of loads on dowel capacity, combined loading of shear, flexure, and axial loads is applied to the dowel bars. As a result, influencing parameters along with these interactions were reported [5], [6].

As shown in Fig.1, the beams with two smooth joint interfaces are selected for this study. The cyclic load (P) was applied at the center unit of jointed concrete. No axial load or axial confinement was provided for all specimens. In addition to the shear force induced due to loading, internal flexural moments are inherently present owing to the loading and support arrangement (Fig.1). Eleven specimens were tested in the series of experiments. Here, the relevant beams are chosen to assess the

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effect of coarse aggregate's spatial arrangement in mortar matrix in use of prepacked concrete as a highlight.

The specimens used for investigation consisted of three units (left unit, center unit and right unit). The units are separated by setting up two smooth joint interfaces. The smooth joints are made with Teflon sheets. These Teflon sheets are inserted to avoid a frictional shear transfer of concrete (Fig.2). The reinforcing bar extends through the three concrete units as shown in Fig.1. Beam 20-CA, Beam 40-RA, and Beam 40-CA are 1500mm in longitudinal length, and Beam 5-M is 900mm. In all the specimens, the center unit is 300mm in longitudinal length. The cross section of Beam 20-CA, Beam 40-RA and Beam 40-CA are 150mm width by 150mm height. Cross section of Beam 5-M is twice the cross section of the others is 300 mm width by 150 mm height. Beam 5-M is twice the other cross sections. The cross sections and bar arrangements of the specimens are also indicated in Fig.1

In this study, three specimens with different aggregate's type and spatial arrangements are presented. In addition, a specimen made with mortar is included in the discussion. Beam 20-CA is constructed of normal concrete where coarse aggregate is distributed within the mortar matrix. Beam 5-M is constructed of mortar only. For Beam 40-RA, natural round gravel is used where particle contact is assured by pre-packing the gravel and then pouring the mortar mix using pipes to fill all the gaps between the pre-placed gravel. Similar method of casting was used for Beam 40-CA by changing the round gravel into the crushed rock generally prepared for truck ballast. Crushed aggregates are thought to bring about stronger mutual interlocking. In casting and compacting concrete of Beam 20-CA and Beam 5-M, phased casting of separation was conducted with plywood's to assure a smooth interface. For prepacked concrete casting of Beam 40-RA and Beam 40-CA, single phase construction was carried out.

For the mortar mixture used for the prepacked concrete, silica sand is used to assure constant flowability. P-type funnel method was used to check flowability of the mortar mix which has been used for management of pre-packed concrete. The measured flow time of the mortar was 44 seconds. And bleeding of 2.8% was measured by the end of 3 hours for the mortar mix.

Cylindrical specimens of 200mm height and 100 mm diameter were used to take samples of each concrete mix and 100mm height and 50mm diameter mortar cylinders were used for mortar mixes. The compressive strength of each mix is presented in Table 1.

Table 1 Material property of the specimens

	Left unit	Center unit (MPa)	Right unit	Maximum aggregate size (mm)
Beam 20-CA	29	37	29	20
Beam 5-M	64	78	64	5
Beam 40-RA	27	27	27	40
Beam 40-CA	30	30	30	40

In all the specimens, deformed bar of 16mm diameter with the characteristics yield strength of 400 MPa is adopted.

2.2 Loading and Experiment Setups

A cyclic loading was applied to the center unit of the specimens (Fig.2). The dowel capacity of the section was computed and tabulated in Table 2. Loading less than the dowel capacity was cyclically applied with progressive increment. The load history per cycle applied at the center of the specimen is shown in Fig.3. The cyclic loading was manually controlled with the speed dial gauge of the universal testing machine. The maximum and minimum ranges of the load applied at the center unit of each specimen are also indicated in Fig.3. The applied load at the center unit was supported by two steel plates resulting in a shear force to the joint.

Table 2 Critical dowel loads of the specimens.

	D_u (kN)	$D_{u,d}$ (kN)
Beam 20-CA, Beam 40-RA, and Beam 40-CA	36	27
Beam 5-CA	106	82

Displacement transducers (Fig.2) were placed at center and supports to measure joint displacement of the vertical slip due to cyclic shear. Gap sensors were installed at the position of the flat interfaces. In addition, except Beam 5-M, reinforcing bar's strain gauges were placed at a multiple of bar diameter's distance away from the jointed face in all three units as shown in Fig.2. Concrete's strain gauges were placed at the top surfaces of the left and right units.

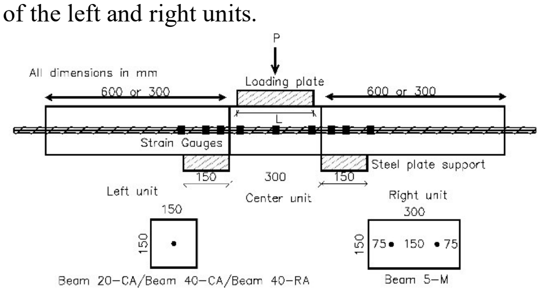

Fig.1 Specimen layout and dimension

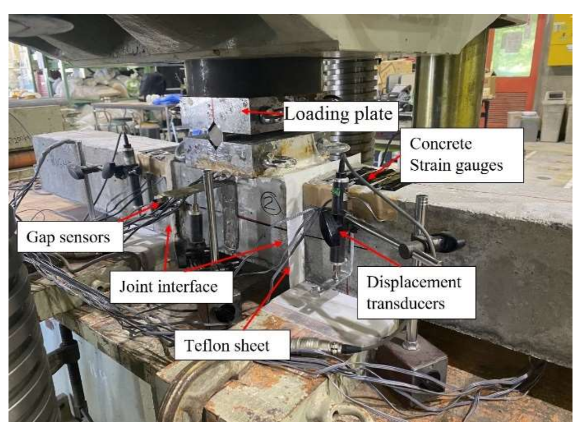

Fig.2 Experiment setup

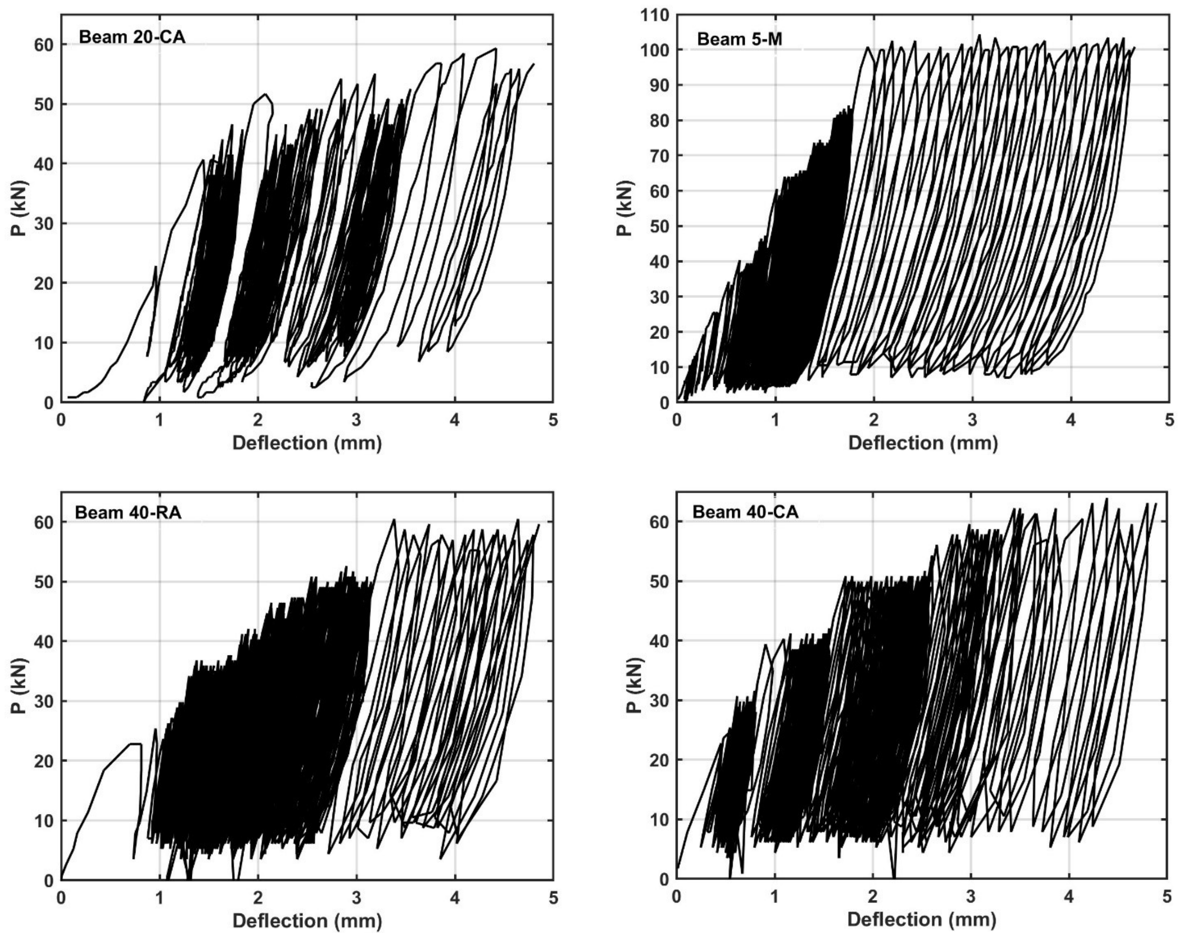

Fig.3 Load versus deflection diagrams from the experiment

3. RESULTS AND DISCUSSIONS

3.1 Experiment Results

The low cycle loading applied to the jointed specimens results in progressive damaging of concrete represented by residual displacement as shown in Fig.3. The cyclic loading is applied with a value less than the dowel capacity. The increment of loading is determined for each specimen without exceeding this capacity. However, each load amplitude and load increment is not uniform due to manual load control system. The damage exponentially increases (Fig.4). N is the absolute number of cycles without the equivalence operation for each load hysteresis in Fig.4. Because the evaluation of fatigue resistance of each specimen based on the N is difficult due to the difference of material constituent, difference of failure mode, the obtained data was simply shown in Fig.4.

Specimens have been shown to undergo significant plasticity attributed to concrete degradation even before the incremental load reaches the dowel capacity of the section (Fig.3). Observation from Fig.3 between sequential cycles in the load versus deflection diagrams of each specimens show plasticity. This plasticity differs depending on the spatial distribution of aggregate.

Beam 20-CA show early plasticity and spread in the load deflection at starting from early loading. Beam 5-M shows early plasticity at the beginning of loading. However, Beam 40-RA of prepacked concrete shows sudden jump at the first stage of loading, then following tighter deflection. Beam 40-CA shows the sudden jump as well after some cycles of loading with less plasticity at the beginning of loads. In all the specimens, the load-

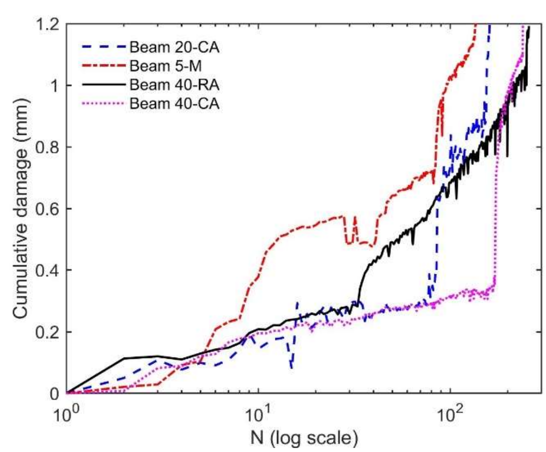

Fig.4 Rate of damage of the specimens

Fig.5 Discrete crack originating from the joint interfaces to the outer surfaces of Beam 1

deflection diagrams exhibit fluctuating at the higher deflection. Sudden deflection jumps of Beam 20-CA, Beam 5-M and Beam 40-CA coincide with progression of discrete cracking at the smooth face of joints (Fig 5). The congestion of load deflection diagram of Beam 40-RA corresponds to mortar crushing and rearranging of aggregate underneath the reinforcement bar.

The cyclic deterioration of concrete is summed up to give the cumulative damage of the specimen. Fig.4 shows the rapid growing cumulative damage of plasticity of 1mm range. The number of cycles (N) for 1mm degradation may depend on the load level strength of concrete and spatial arrangement of aggregates. The deterioration observed within the joint interfaces is either due to a discrete crack propagation or the bearing damages of concrete beneath dowel bars. In fact, in both types of deterioration, increased deflection resulted in splitting at the top and bottom surfaces of the specimen.

Deterioration type depends on the distribution of aggregate and type of aggregate adopted for the specimen. All the specimens demonstrated a discrete crack propagation before the specimen reaches its critical dowel capacity (Fig.5). Similarly, part of the eleven specimens in the series of this experiment [7] also showed concrete degradation leading to splitting failure before the joints reached their dowel capacity.

The discrete crack propagation was observed to progress mostly between the mortar and coarse aggregate interfaces for normal strength concretes. Although Beam 5-M possesses the highest compressive strength and double in cross section from the other sections, this specimen shows early deterioration and the surface longitudinal crack propagation. In addition, crack propagation was initiated in the earlier cycle of loading followed by vertical and horizontal cracking. Even though Beam 5-M has higher compressive strength, the capacity of the section exhibits to be lower (Fig 7). The 1mm damage shows the initial deterioration of the specimen attributed to loss of bond (Fig 7A). The 5mm cumulative damage shows the overall performance of the specimens. That is the crack propagation of the specimen. Early deterioration of the specimens is observed for specimens with mortar mix and with spatially distributed aggregate with no contact (Fig 7B).

The performance of joints shows dependency on the distribution of aggregate and strength of concrete. For Beam 20-CA, the crack was observed to progress from the joint to the top surface of the beam mostly from

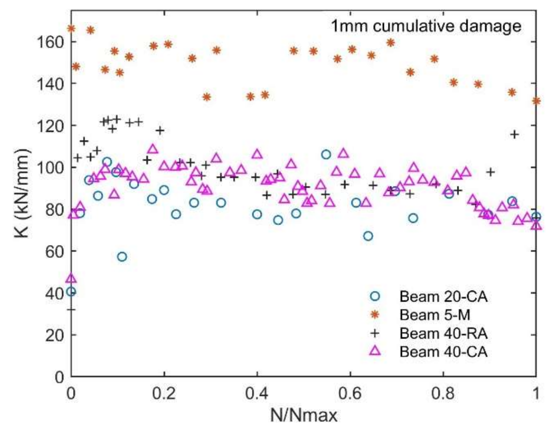

Fig.6 Stiffness variation due to cycling, cycle normalized to the maximum cycle within the specimen

the joint to the top surface of the beam mostly following the path of mortar-to-aggregate interfaces (Fig 5). Beam 40-RA exhibits different crack propagation on the left and right unit of the specimen. The left unit's final failure is owing to the crushing of concrete under the bar and the right side's crushing and finally splitting.

3.2 Discussions

Stiffness degradation of reinforcing bars is reported to be due to the local flexural yielding of the dowel bar when connected joints exceed their dowel capacity. The dowel stiffness degradation under reversed cyclic load was investigated analytically and experimentally [1], [4]. The effect of combined loading of axial and shear load in axial stress reduction of reinforcement bars has also been investigated [5], [6]. The concrete degradation is only expected to occur after the critical dowel load capacity is reached and it is limited to joint surface spalling of concrete beneath the bars. It is noted that the experimental results in this study are obtained before dowel capacity of steel bars (Fig.3). Due to the experiment setup adopted, these joints of the specimens were subjected to a cyclic moment in addition to the shear force. In 1mm cumulative damage for all joints, plasticity shows to be highly incremental (Fig.4). In addition, the stiffness of Beam 20-CA, Beam 40-RA and Beam 40-CA within these 1mm cumulative damage shows increase right after the initial loading, and after attaining some level, behaves constant (Fig 6). For Beam 5-M, the stiffness is high at the initial loading and a

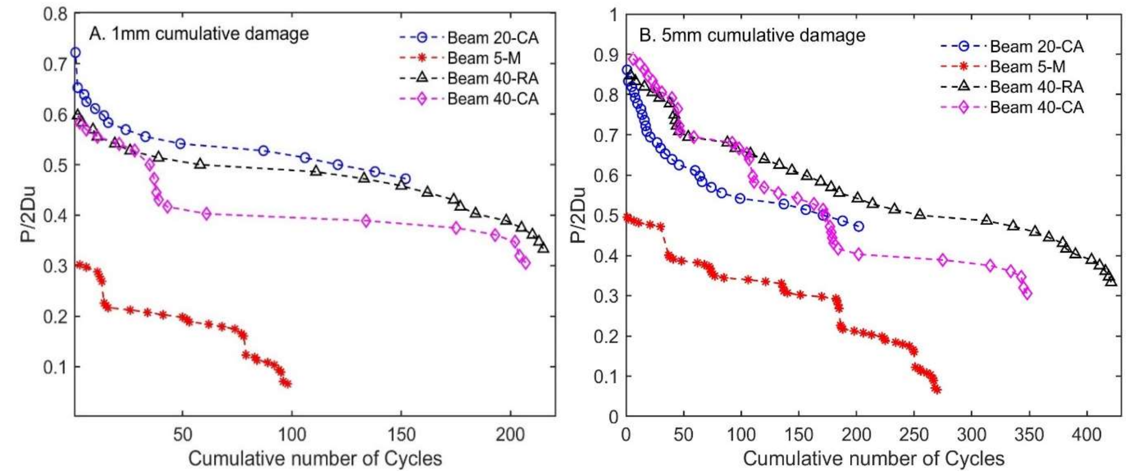

Fig.7 Number of cycles the specimens withstands for 1mm and 5mm cumulative damage respectively, normalized load with the critical dowel capacity.

constant level is achieved. The stiffness of the section has shown to depend on the compressive strength of the material. Within the 1mm range, Fig 6 shows that there is no significant reduction in the stiffness. This can be confirmed from load deflection diagram where the path of the unloading and reloading curves is mostly parallel (Fig 3). It may demonstrate the stable plastic damaging of concrete before the full dowel capacity. Damaging of concrete is later accompanied by the yielding of steel bars.

According to Timoshenko's [8] beam on elastic foundation theory (Eq. 3), the continuous reaction of the foundation (q) is proportional to the deflection (y). The constant is defined as subgrade stiffness (k) and is the reaction per unit length when deflection is equal to unity. In this experiment constant k values have been obtained. But a permanent deformation exists, thus RC sections fails to conform beam on elastic foundation principle. This can be attributed to the subgrade's brittle behavior.

$$q = -ky \tag{3}$$

The concrete damage initiated at the joints is associated with the formation of cracks at the top, bottom and side faces of the joint on the specimen. The splitting of concrete originated from the joint interface and progressed both at the top and bottom of the specimen. This failure is initiated due to the initial concrete degradation in a form of bond failure. This can be observed in Fig 7A where it shows fatigue behavior for 1mm cumulative damage. The bond deterioration of the specimen Beam 20-CA, Beam 40-RA and Beam 40-CA are similar. This can be due to the specimen's similar concrete strength. Beam 20-CA shows early deterioration as compared to Beam 40-RA and Beam 40-CA (Fig.7A). This can be explained due to the early application of higher load levels (Fig 3). Bond failure is further facilitated by the fatigue load applied to the joints as discussed in this study.

In addition to strength of the concrete, effect of aggregate distribution has shown substantial impact in the fatigue life (Fig 7B). As there is no coarse aggregate in a mortar mix, strength is higher. Consequently, the mortar specimen showed early deterioration and the specimen with aggregate contact possessed higher resistance to the low cycle of loads. The high strength concrete has shown to have comparatively lower fatigue performance in comparison with the normal strength. Despite the type of aggregate (round gravel or crushed aggregate), the role of spatial aggregate distribution is substantial for cyclic performances. As the presence of aggregate interrupts, the early crack propagation (Fig.7B). Even under repetitive loading the specimen made with 40mm gravel (round aggregate) has shown progress lower residual deflection (Fig.7B). This is thought to be attribute of local crushing and rearranging of particles within the joint interface.

Beam 20-CA has been subjected to higher load level at early stage of loading and as it is seen from Fig 7A that a lesser number of cycles are required for the section to reach 1mm cumulative damage. Even though Beam 40-RA is subjected to higher loads within 5mm cumulative damage (progressively increased as shown in Fig 3), it has greater tolerance for the fatigue load as compared to Beam 20-CA. This can also be confirmed for Beam 5-M, where lower load level is applied. Hence, clear observation can be made with regards to the effect of load levels on the performance of the specimens.

Limiting attention to the case of smooth joint interfaces, the interaction of cyclic degradation of concrete subjected to cyclic shear and moment need to be considered in design to assess performance of structures during service years.

4. CONCLUSIONS

The effect of coarse aggregate arrangement on dowel performance was discussed and the following remarks are made.

(a) Splitting crack at the bottom and top of the concrete specimens was originated from the joint interface. This crack propagation progressed to the surface from the bar-to-concrete interface.

(b) Incremental plasticity was observed in the joint sections related to concrete damages.

(c) The incremental damaging shows dependency on the spatial distribution of coarse aggregate particles. Between the two extrema of mortar and pre-packed concrete, the reduced crack propagation was shown in the presence of coarse aggregates.

(d) The incremental permanent deformation within the section may identify that "beam on elastic foundation theory" may not function for modeling the performance of jointed concrete.

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