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Behaviour of Sandwiched Concrete Beam under Flexural Loading

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***Abstract*— Beam is an structural element whose main function to carry external load in the direction perpendicular to the axis of the beam. Theoretically, it is assumed when the concrete starts to crack the tension in the concrete can be neglected. Bending moment at the cross section at the location of the crack is carried by a pair of coupled forces; compressive force happens in the compressive zone above the neutral line and the tension force happens in the tension zone below the neutral line. In this kind of flexural respons, it seems that the middle part of the cross section in the vicinity of the neutral line does not have to carry any stress. This Fact gives the idea to combine normal concrete and light weight concrete in a sandwich structure.**

The main intention of this investigation is to conduct an experimental study on the flexural behavior of three layer concrete sandwich beam. The central layer is made of light weight concrete with compressive strength of 30 MPa. The center layer is sandwiched between two outer layer made of normal concrete with compressive strength 50 MPa. The test was conducted on four beams speciments with dimensions of 2100 mm in length, 100 mm width and depth of 200 mm.

Flexural beam subjected to static and cyclic load. Observation on load-deflection curves show that flexural strength capacity is determined by the loading systems, the contact conditions of the interfaces in composite system due to the use and the material properties of connectors in the middle part of the concrete beams.

***Keywords*— Sandwich, Flexural, Static, Cyclic, Connector**

I. INTRODUCTION

In an element of concrete structure, under bending moment, the majority of the forces only act on the top and bottom part of the cross section. Therefore, it is not efficient if the part of the cross section in the vicinity of the central line that is subjected to a relatively small force is made of the same material as the one that carries most of the load.For the part of the cross section that carry small portion of the load, light weight concrete that has relatively lower strength but has much lower density can be used. In contrast, the part of the cross section that has to support the majority of the load can be constructed using normal concrete that has relatively high strength. The combination of these two different type of concretes in a form of concrete core layer that sandwiched between two skin layers in a concrete structure is known as concrete sandwich structure.

The use of normal concrete as skin layers in a concrete due to its high strength or sometimes known as High Performance Concrete (HPC) has some advantages, which includes: High strength (>41 MPa), resistance to hostile environment, high stiffness, low thermal expansion, andsmall shrinkage and creep. However,several research conducted in the past show thatHPCtend to be produced from heavy weight concrete that means, if implemented, the optimum design can not be achieved(Besari, at.al.,1999).

According to ACI *Manual of Concrete Practice* (1995), concrete with specific gravity less than 1840 kg per m^3can be categorized as lightweight concrete sebagai beton ringan. It is well known that aggregate take the biggest proportion in concrete mixtures. By replacing conventionalaggregateby ArtificialLight Weight Agregat (ALWA) the total weight of the beton andstructure can be reducedwhich in turn will automatically reduced the dimensions of the structure.Therefore, the optimum design can be achieved.

However, lightweight concrete has its own weakness such as lower stiffness and higher brittleness in addition to high shrinkage and creep behavior. Disamping mengefisienkan increase the efficiency of the concrete layer in resisting the flexural load, secara teoritis, by considering the advantage and disadvantage of high strength concrete and light weight concrete, bycombining these twoconcrete into what is known as compositesandwich,the two concrete are compliment each other.

The problems that often emerge in sandwitched concrete structure is bonding between the two layers of different concrete types. Therefore, it is very likely that the failure is caused by debonding. Therefore,in designing concrete sandwich structure, not only we have to understand the behavior of the individual element, but also bondsbetween the two concrete layers of sandwiched concrete structure. One of the main requirment for the composite sandwich to support loading is compatibility between loading and deformation. Therefore, the sandwiched concrete structure must be able to act as a monolithic composite structural element. As has been mentioned before, this is determined by bonding between surface and core layer.To obtain high quality bonding between those two layers in such a way that monolithic composite condition is fullfiled, connectors will be required to joint the surface and core layer forming the sandwiched concrete structure. A study of the relationship between the flexural deformation and the strength of the sandwiched concrete structure is required.

II. LITERATURE REVIEWS

A. Sandwich Structure

Sandwich structure is a structure that is composed of two strong and stiff thin layers made of solid material that are separated by a thick layer of low density material with lower strength and stiffness than the two other layers (Callister, 1997). The two thin layers are called skins and the mid layer is known as core(Gambar 2.1). In most cases (Corden, 1990), An efficient sandwich structure can be obtained if the weight of its core is equal to the total weight of its skins.

According to Jones, R.M. (1975), sandwich structures combine the superiority of the materials used as its layer, namely, the high strength and stiffness of the skin layers and the low density of the concrete core layer..The result is a structure that is strong and stiff yet lightweight.

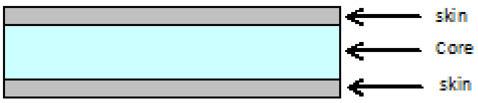


Fig. 1 Concrete sandwich structure

According to Van Straalen (1998), attentions must be paid on several issues related to the core layer, i.e,

- The core layer must be strong enough in perpendicular direction to the skin layers, such that the distances between layers are constant.
- The core layer must be stiff enough under shear loading, such that when the sandwich structure bends the skin layers do not slide against each other. If the layers slide, the composite effect is lost. As a result each layer acting independently.
- The core layer must be stiff enough such that the skin layers stay level under bending load. If the core layer is not stiff enough delamination will happen.

For the skin layers the following need to be considered:

- The skin layer must be able to withstand tension, compression and shear loads on the x-y plane of the sandwich structure.
- The skin layers must also be able to support bending load, that is tension load on one side and compression load on the other.

The material of the skin layers can be isotropic or anisotropic. Each skin layer in general is made of same material. The main material properties of the skin layers is elasticity modulus, tensile and compressive strength, and Poisson's rasio.

B. Mechanical Behavior of Sandwiched Beams

The mechanical behavior of the sandwich beams under external and other types of loading is very complex. When a composite beam structure is loaded under a flexural loadingat the service load level, the possible composite condition that occurs in the beams can be classified into: Fully composite, when all layers of the composite are jointed in a way such that the composite structure can act as a monolithic structure. The Connectors must be able to transform all longitudinal shear forces such that the resulted bending stresses distribution is continuous over the cross section of the beam (Fig. 2.a).
Partial composite, i.e,the connectors that connect different composite layers transfer part of the longitudinal shear force in the beam (Fig. 2.b).

Non-composite, if there is no bonding between each composite layer that is where the core layer and and the skin layers of the beam acting independently under flexural loading. (Fig. 2.c)

C . Ductility

Ductility is the ability of a structure or elements of structure to resist dominant inelastic responses while maintaining most of their initial strength in carrying the load. Ductility of a beam is defined as the ratio of ultimate deformation and yield deformation. Deformation considered can be kelengkungan, displacement,or rotation, according to SK SNI 1991, beam structure is considered to be ductile if the ductility factor of the cross section or structure is greater than 4.0 (p > 4).

III. METHODOLOGY

This study is based on bending test of the sandwich in a laboratory condition. Three speciments are used with the following specifications: the skin layers are precast concrete (NWC) with depth of 6 cm and the core layer (LWC) with depth 8 cm cast between the two concrete precast layers age 4 days.

A. Speciment Preparation

Basically the sandwich beam is a laminated beam in which the number of laminates or layers is three. The top and bottom layer in this study are called surface layers. In this study the surface layer is a precast concrete with dimensions 2100 mm lengthwise, breadth 100 mm anddepth 60 mm. at the center of the skin layers we put a reinforcement grid 70 mm x 150 mm. The number of longitudinal reinforment bar for each beam is 3 with diameter of 6 mm.Out of 4 beam speciments, two of them had a single row connectors attached to the middle part of the longitudinal reinforcement bar, as can be seen on Fig. 4. The surface of the precast concrete that going to touch the core layer were not roughened as the roughness effect is negligible.

The middle part of this sandwich, known as core, is 2100 mm in length, 100 mm in width anddepth of 80 mm. The core is a cast in-situ placed between the two surface layers.

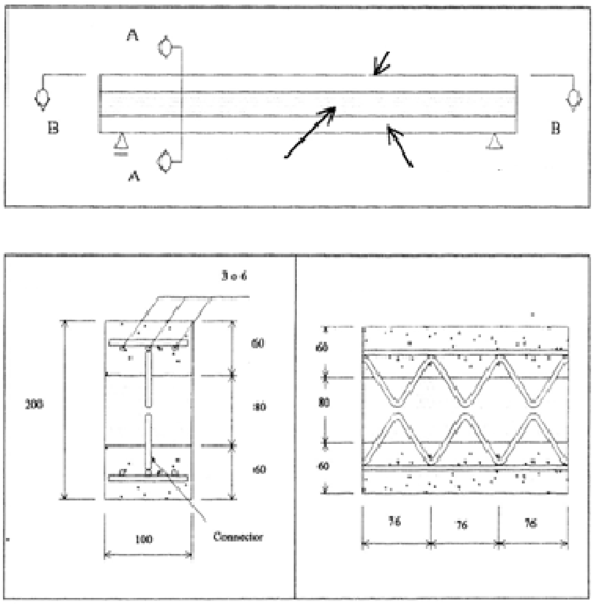


Fig. 2 Sandwiched concrete beam stucture

B. Instrumentation

Instruments used in sandwiched beam testing in this study are:

a. Reinfocement bar and concrete strain measurement aparatus
b. Deflection measurement aparatus
c. Slipage measurement aparatus
d. Rotation measurement aparatus
e. Load cell

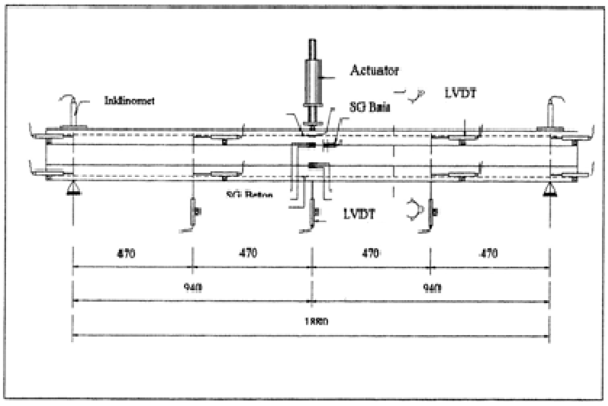


Fig.3 Position ofthe measurement apparatus in sandwiched concrete beam testing

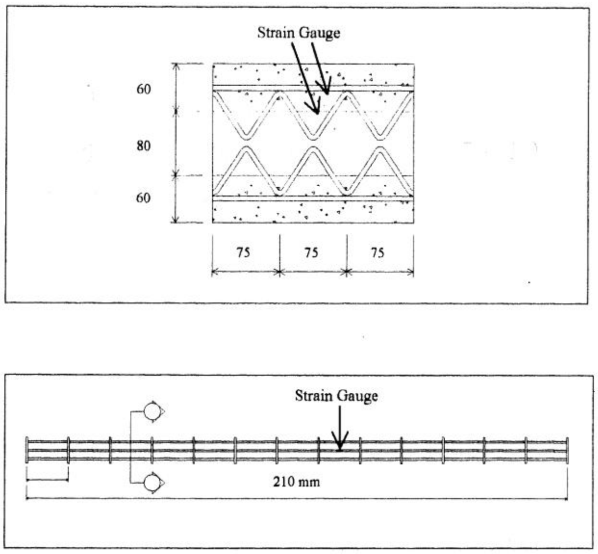


Fig. 4 Positions of the strain gauges on connector dan longitudinal reinforcement bars

C. Beam Loading

The testing was conducted on 28 days old beams. Monotonic and cyclic loading were performed.Beam specimens were laid horizontally in a loading frama. Both ends of the beam were simply supported using pin and roll supports. For cyclic testing, additional supports were employed so that the beam can handle cyclic load.

For monotonic testing, beams were loaded in downward direction at the mid span until they were failed.For the case of cyclic loading, the loading system employed isquasi-static reversed cyclic loading, i.e.,the specimen is incrementally loaded in certain direction, for example, downward for compressive load and followed by reverse loading.

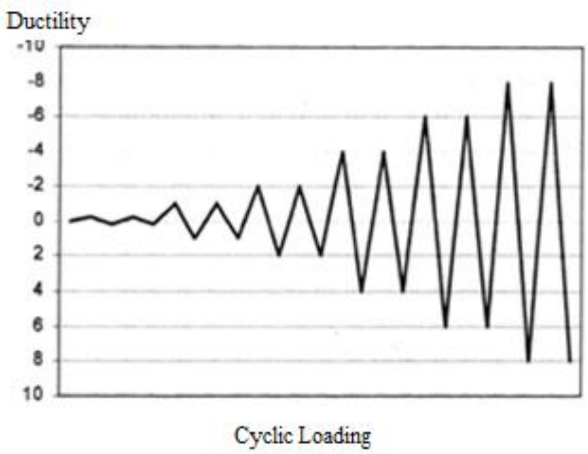


Fig.5 Loading Cycle

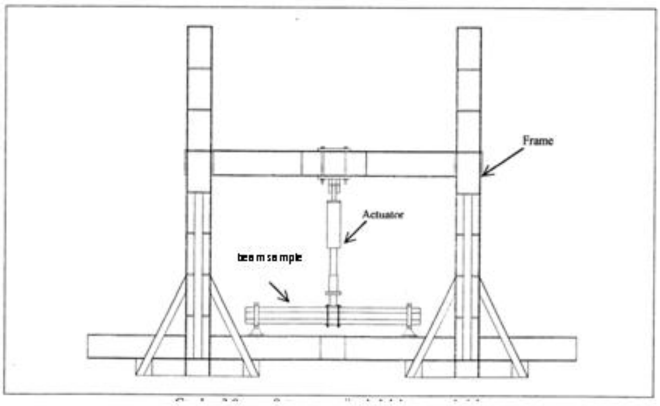
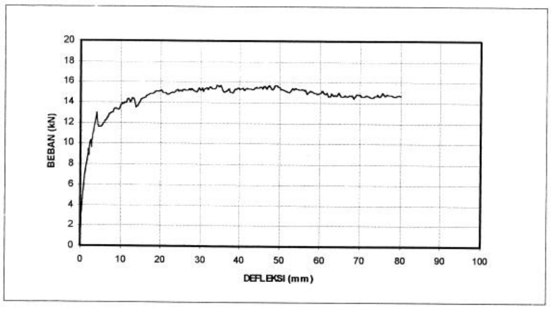


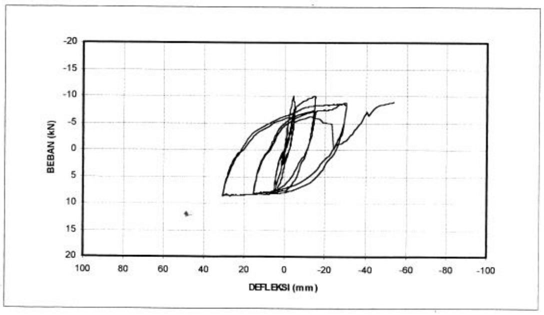
Fig.6 The setting of sandwiched concrete beam testing

IV. EXPERIMENTAL RESULT AND DISCUSSIONS

Based on data obtained during testing, the flexural strength of the beam for a particular loading stage can be computed. The loading for dynamic testing of N-L-N non-connector beams, N-L-N connector, and N-N-N connector were conducted based on the monotonic loading on N-L-N non-connector beams. The beams were design to possess similar bending moment in tension and compression directions. Therefore, the dimensions of tension and compression bars were the same.

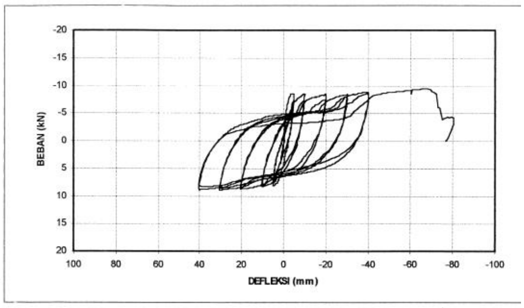


(a)

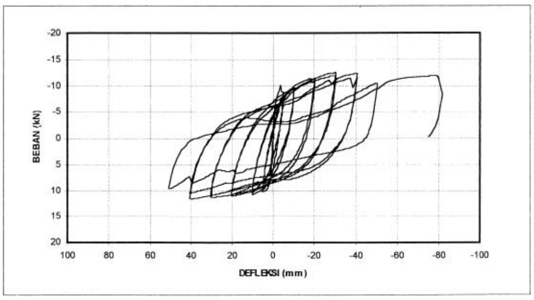


(b)

Fig. 7 Load-deflection hysteritic curves for beam
(a) N-L-N non connector (monotonic),
(b) N-L-N non connector (daktilitas 6)



(a)



(b)

Fig. 8 Load-deflection hysteritic curves for beam
(a) N-L-N connector (ductility 8),
(b) N-N-N connector (ductility 10).

a. N-L-N Non connector Beam

These beams were tested under monotonic loading. The bending moment that causes the initial crack on the beams is 3.299 kNm. The bending moment that causes the reinforcement bar start to yield is 6.119 KNm. The maximum bending moment that can be with stand by the beam is 7.388 kNm.

b. N-L-N Nonconnector Beam

These beams were tested under cyclic loading. The bending moment that causes the initial cracks on the beams is 1.993 kNm in compressive direction dan 1.335 KNm in tension direction. The bending moment that causes the longitudinal reinforcement to yield is 4.056 kNm in compressive directionand 3.784 kNm intension direction. Maximum bending moment that can be supported by the beams is 4.094 kNm in compressive directionand 4.056 kNm in tension direction.

c. N-L-N Connector Beam

These beams were tested under cyclic loading. The bending moment that causes the initial cracks on the beams is2.496 kNm in compressive direction and 1.922 KNm in tension direction. The bending moment that causes the longitudinal reinforcement to yield is4.023 kNm in compressive direction and 3.854 kNm in tension direction. The maximum bending moment that can be carried by the beams is 4.315 kNm

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d. N-N-N Connector Beam

These beams were tested under cyclic loading. The bending moment that causes the initial cracks on the beams is3.346 kNm in compressive direction and 3.346 KNm in tension direction. The bending moment that causes the longitudinal reinforcement to yield is4.225 kNm in the compressive direction and 4.803 kNm in the tension direction. The maximum bending moment that can be carried by the beams is 5.635 kNm.

TABLE I
FLEXURAL STRENGTH FROM THE TEST RESULTS

Remarks	N-L-N Nonconnector	N-L-N Nonconnector	N-L-N Connector	N-N-N Connector
M_{cr}^{+} (kNm)	-	1.335	1.922	3.346
M_{cr}^{-} (kNm)	3.299	1.993	2.496	3.346
P_{cr}^{+} (kN)	-	2.840	4.090	7.12
P_{cr}^{-} (kN)	7.020	4.240	5.370	7.12
P_{cr} theoretical	7.994	7.178	7.830	7.639
M_{y}^{+} (kNm)	-	3.784	3.854	4.803
M_{y}^{-} (kNm)	6,119	4.056	4.023	4.225
P_{y}^{+} (kN)	-	8.050	8.200	10.220
P_{y}^{-} (kN)	13.020	8.630	8.560	8.990
P_{y} teoritis	9.294	9.243	9.285	9.015
M_{u}^{+} (kNm)	-	4.056	-	-
M_{u}^{-} (kNm)	7.388	4.094	4 315	5.635
P_{u}^{+} (kN)	-	8.630	-	-
P_{u}^{-} (kN)	15.720	8.710	9.180	11.990
P_{u} theoretical	11.798	11.751	11.791	11.806

If the strength coefficient (θ) for every loading condition in monotonic testing is 1, then the value of the ratio of the strength between monotonic and cyclic testing can be seen in Table II.

TABLE III
COMPARISONS OF STRENGTH RESULTED FROM MONOTONIC AND CYCLIC TESTING AT EACH LOADING CYCLE

Remark	N-L-N Nonconnector	N-L-N Connector	N-N-N Connector
Fracture Strength (θ^{+})	0.4	0.581	1.424
Fracture Strength (θ^{-})	0.6	0.756	1.424
Yield Strength (θ^{+})	0.62	0.630	0.785
Yield Strength (θ^{-})	0.66	0.657	0.690
Ultimate Strength (θ^{+})	0.549	0.584	0.763
Ultimate Strength (θ^{-})	0.550	0.584	0.763

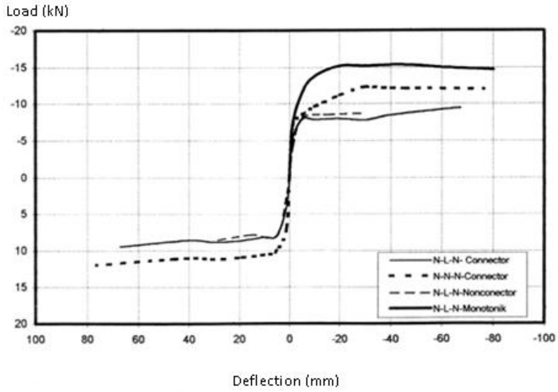

Fig. 9 Load-deflection curve for idealized loading

V. CONCLUSIONS

a. Load-deflection hysteretic curve obtained from cyclic testing shows that the shapes of the curve in tension and compression directions is more or less similar.

b. Ductility that can be responsed by the beams depend on the type of loading, the use of connectors, and the quality of the core concrete. For N-L-N nonconnector beam the ductility of the monotonic testing can reach 16, while N-L-N connector beam ductility only reach 8, and NNN beam ductility can reach 10. There was a degradation of strength and stiffness at the even cycle ductility caused by slippage at small load (*pinching effect*).

c. Bonding between the two different concrete layers heavily influenced the composite behavior of the beams.

d. The flexural strength of the sandwiched concrete beams is dictated by the types of loading, the use of connector, and the quality of the core concrete.

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