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Damping Factor of Precast Concrete with Wet Connection

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Abstract— **This research aims at determining the behaviour of structural elements of precast reinforced concrete beams which are connected with wet and dry connections. Specimen used was 30 Mpa reinforced concrete beams with 6 pieces of 8 mm diameter main reinforcement which are placed on two rollers at the joint pedestal of each end and has a rectangular cross section of prismatic 10x18 cm2. Wet connection is a connection that uses a polymer concrete material of 40 MPa with a grafting method using prepacked method. The result of the research is expected to contribute to the development of precast concrete in building construction in Indonesia. In the elastic condition, the beam monolith has the largest natural frequency of the value, but a wet connection beam has a low natural frequency value. The difference of this natural frequency value is also equal to the condition of crack and ultimate.**

Keywords— **Element, reinforced, connection, prepacked method, frequency.**

I. INTRODUCTION

Basically, there are only three structural elements in the portal system of precast concrete structures building namely column, beam and plate in which each of them has a role in bearing the burden. Framework structure consisting of column and beam in several places in Indonesia is still done in a cast on the spot. In anticipation of the development of construction work system which is more quickly and economically, the manufacture of concrete columns and beams have started to work in precast (especially in big cities) at the factory and connecting the beam and column element is done in the work field.

The connection part should be able to distribute the forces and moments acting on the connected elements that are flexible moment, torsion moment, share force and normal force. In addition to buildings in the earthquake zone, the existing connection can add the structural damping toward the dynamic force of the earthquake. On the dynamic behaviour, there is one thing that has always eluded from the observation that is how the dynamic behaviour of a structure in damping the vibration when the structure was fractured. In addition, it needs the observation to the damping behaviour structure when the structure reaches ultimate conditions. Precast structural capability in damping the dynamic force is not only influenced by the type of connection, but also by the condition of the structure, whether the structure in elastic or crack condition.

Attenuation observation made by looking at the dynamic behaviour of an object or structure is the structural response due to dynamic load. Dynamic load is a load that changes with a specific function or random toward the time. The structure has a natural frequency that equals to the number of degrees of freedom structure. If the external force acting on the structure has a certain frequency and its magnitude equals to one natural frequency of the structure, therefore the structure will provide a resonant response at one vibration mode of the structure. From the resonant pattern the ability to reduce the structural dynamic style can be known

The purpose of this research is to determine the dynamic behavior of precast reinforced concrete beam which are placed on simply supported. Dynamic load applied at midspan and then the attenuation was examined when resonating. Attenuation study of reinforced concrete structural elements with the connection is done on the three structure conditions, namely elastic condition, crack initiation and ultimit conditions. Observations were then compared with the behavior of the beam without a connection.

The position of beam is placed to get a good resonant pattern. Good resonant pattern obtained when the pattern of structural deformation caused by external forces at mid span is equal to its mode shape. From the resonant patterns obtained the attuanitaion structure can be measured. Attenuation measured in this study is the attenuation at the resonant structure on the first vibration mode, or dynamic load that has the same frequency as the first natural frequency of the beam structure vibration mode

The use of polymer concrete to the wet connection on precast reinforced concrete structural elements will change the behavior of static and dynamic elements of the precast reinforced concrete structures. This change will

result in price differences stiffness, ductility, natural frequency, the pattern of resonance and attenuation structure. Damping in precast structures occurs in the material, cracked area and connection. On the material, the viscous damping was occured in the cracked area and friction damping connections was also occured.

Model specimens is a precast reinforced concrete beam with rectangular cross section that has 6 (six) pieces main reinforce. When testing, the beam is placed on two support joints and roll to get a statically determinate structures. The number of test specimens for each test parameter group are 4 (four) beams. These groups are the first group that is the group with two wet connections, the second group is with a single wet connection and the third group is a group with no connection (monolith). The connection beams is placed in the middle span for a single connection and at one third of span for two connections.

The beam's position is placed on the configuration that produces the smallest cross-sectional moment of inertia and in line with the work loaded. Loading was performed at mid span both during static load and dynamic load. Method of dynamic testing with testing capital is a non-destructive testing because the load is quite small and via the accelerometer, the beam response to dynamic load can be determined.

1.1 Transversal Vibration of Continuous Structure

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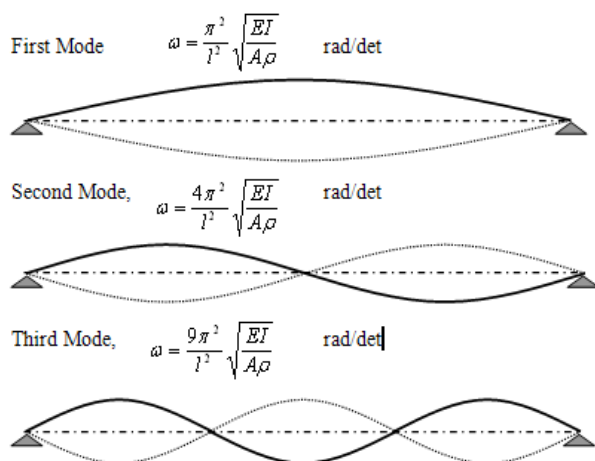

First Mode $\omega = \dfrac{\pi^2}{l^2}\sqrt{\dfrac{EI}{A\varrho}}$ rad/det

Second Mode, $\omega = \dfrac{4\pi^2}{l^2}\sqrt{\dfrac{EI}{A\varrho}}$ rad/det

Third Mode, $\omega = \dfrac{9\pi^2}{l^2}\sqrt{\dfrac{EI}{A\varrho}}$ rad/det

Figure 1.Mode Shape and frequency of transversal vibrations of beam

In structure analysis using the SAP program, precast concrete beam can be modelled as a frame or a solid object. Beam analysis using the energy method to get the shape of two-dimensional mode is only plane frame. Beam analysis using SAP to gain three-dimensional of mode shape on the three principal axis that are x, y and z.

Thus the analysis is close to the real condition when the experiment was carried out.

1.2 Damping in the Structure

Basically, there are two types of structural vibration, they are: (1) steady state vibration that is caused by the continuous passage of the engine such as generators, air conditioning and (2) transient vibration which is caused by a disturbance within a specified period such as a vibration in the rail to road pavement due to the pace of the train, or a bridge that gets the load of passing vehicles. In some vibration excitation in the steady state vibration control can be done by moving the excitation source. Mass of the vibration generator is to give effect to the natural frequency of the buffer structure. For example, in machine building can be put on the ground floor which has a large stiffness. Large mass of the machine can be offset by the large stiffness of the structure to make the change of $\sqrt{k/m}$ value is small.

Increasing the damping in the structure can reduce the structural response due to excitation of a given load. So, if the damping in the structure can be increased, the vibration structure can be minimized and the dynamic voltage in the structure can be reduced so that the structure age will be longer. Increasing the damping in the structure is not always easy, it can be more expensive, even a waste of energy. Some structures require a good control of the damping toward the inside excitation force, for example the crane structure requires a large attenuation of the response toward the momentary power.

In the object tested, the type of wet connection is used that is the connection by casting on the spot at the location of the connection using a better material than the joined material. The connection location to the tested object with a single connection in the middle of the span is 60 cm from the pedestal, while the tested object with two connections located on the one third of the span that is 40 cm from the pedestal (Fig. 2).
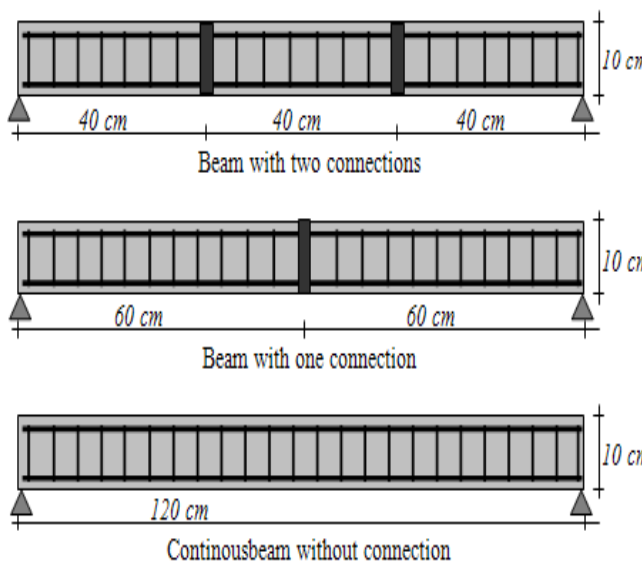
Figure. 2. The location of the connection on the test object

Connection system of the precast reinforced concrete element is using a wet method with repacked. Reinforced concrete structural element that will be connected to, should be casted at the first and on the connected part, the main reinforcement is to be exceeded with the main reinforcement of other beam elements (Figure-3). The main reinforced concrete connection is tied with concrete wire and then the connection may be filled with polymer concrete material. In prepacked system the aggregate is included at the first time
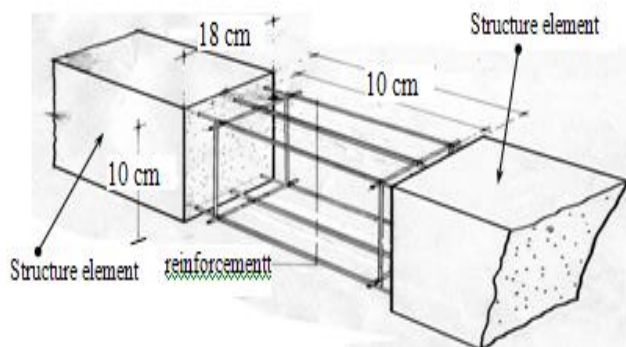

Figure-3.The reinforced connection in the wet connection
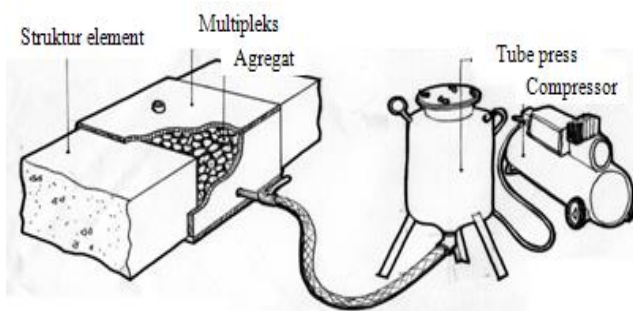

Figure -4. Method of connecting by prepacked

On the connection, then using a tube press compressor as shown in Figure-4, the polymer paste is put into the aggregate space. Before aggregate is included in the connection, firstly, the connection is covered by the multiplex at the bottom and right and left side.

To prevent the leakage of the polymer paste, the plywood section dealing with concrete is covered with polymer sealant. After sealant is dry, all reinforcing on the connection is smeared with methyl ethyl ketone peroxide, then oven dried coarse aggregate with a size equal between 10 to 20 mm is put into the mold. From the side that has been drilled, a hose with the tap control is inserted to enter the polymer paste with fly-ash filler. Before the pasta polymer is inserted into the tube press, it should be stirred smoothly to prevent any solid grains from fly ash filler. Drainage of the polymer paste from the tank into the mold prepacked is done with the help of compressed air pressure of approximately 2 bars.
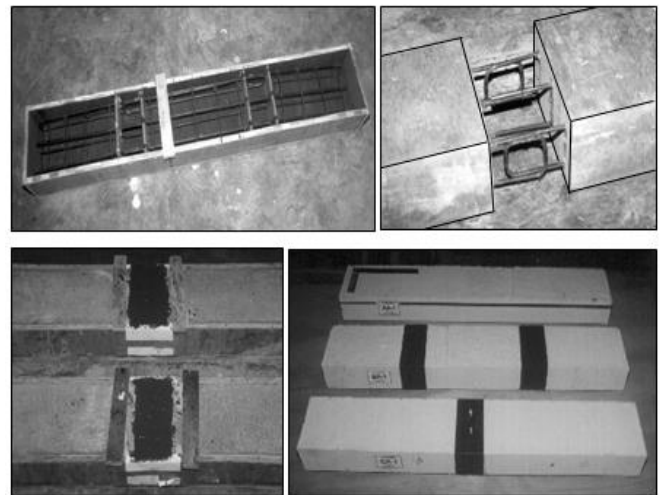

Figure-5.wet connection (clockwise): specimen mold, reinforcedment in the joint, the ready specimen tested and connection after the connection by prepacked.

By using grafting polymer, the precast concrete elements connection can be done quickly. Depending on the amount of methyl ethyl ketone peroxide, the hardening can be accelerated up to 15 minutes. In making this specimen, the hardening process occurs after three hours. Figure-5 shows the test specimen molds and reinforced beam on the connecting area before the connection with prepacked method is done. Capacity on the junction cross-section greater than the capacity of on the beam cross section to be connected. The existence of double reinforced in the joint and connective materials using polymer concrete material 40 MPa is the cause of much greater capacity than the cross section on the junction between the beams to be connected.
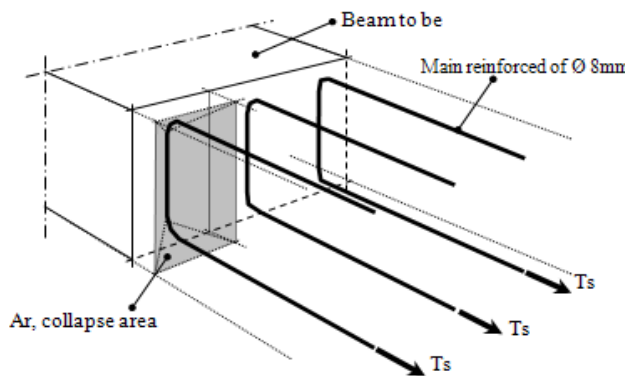
Figure-6. Collapse mechanism in wet connection in the analysis of cross-connection capacity wet.

The main reinforcement in the connection area works fully because of the long loop at the end of the connection is sufficient for melting in the reinforcement so that the reinforcement looses from the connective material. The collapse mechanism of reinforcement loop junction is shown the figure below (Figure-6).

On the collapse mechanism of the wet connection due to tensile rebar Ts on the collapse of the polymer concrete as a material connection. Collapse that occurred is in the form of the field that makes 45of angle toward the gravity that will experience the pull of fc, which is

$$f_c = \frac{1}{3}\sqrt{f_c'}$$

(1)

The amount of tensile force required for breaking down or removing the broad field of polymer concrete with A_r is

$$T_s = A_r . f_c$$
(2)

If the magnitude of the T_S force is greater than the Ts force when melted, then the connection reinforcement works fully and on thesection capacity analysis, the number of reinforced is double of the amount of reinforced concrete beams to be connected

2. Measuring Attenuation Structure

Some of the parameters are used to measure the effective damping which is based on the complex physical phenomena and forms of dissipation energy. This different amount of attenuation is also caused by the types of testing methods of damping structure.The amount of damping in the structures also depends on the configuration of the load on the structure. For example, to analyze two concrete prismatic beam elements with the same length of material will get a load in two different places. If the beam is placed on a pedestal and get two loads at midspan, the stiffness of the beam is P-δ for k1. It will be different if the load is not done in the middle of the

span, but within a quarter of the span of the foundation, the P-δ stiffness is k2. From these two conditions, the same concrete structure has a different stiffness which means it also has different natural frequencies. Stiffness and frequency differences also occur if the same concrete beam elements but different placement systems such as cantilever beam as the example is placed at one end clamped and the other end is free.

Attenuation structure can not always be measured from the response of the structure after getting a load out, because there are some structures such as the ship construction that getting a load from the collision of ocean wave or offshore construction where the load comes from the ocean waves. Measuring the decrease of oscillation amplitude in the structural response due to instantaneous force is one of the ways to get the structure damping. In the resonance test, the damping analysis can be performed. In this kind of test, the structure is given the same frequency that equals to one of the natural frequency of the structure. If X static is not known, then the Q factor can be searched by using the half power point method. In this method, it requires the accurate measurement of the vibration amplitude when the structure is resonating.
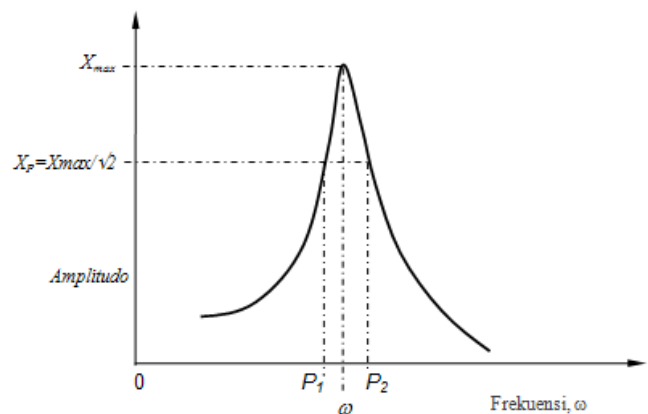

Figure-7. Amplitude-frequency response graphs on a single resonance

If the damping is assumed small, which is the majority of the structure case, $\omega = \sqrt{k_{\text{mode}}/m_{\text{mode}}}$ where k_{mode} and $m_{\text{mode}}$is effective stiffness and mass of the structure at a specific vibration mode. From the resonance pattern of Figure7,it can be detected resonance frequency of ω and the maximum amplitude X_{max}. Then the half power point is obtained at amplitude $X_P = X_{\text{max}}/\sqrt{2}$ and its frequency is $P_1$and P_2. Because the lost energy at each cycle is equal to X^2, the energy is lost by 50% when the amplitude is decreased by a factor of $1/\sqrt{2}$.

Because

$$X = \frac{F/k}{\sqrt{\left[1-\left(\frac{v}{\omega}\right)^2\right]^2 + \left[2\zeta\frac{v}{\omega}\right]^2}}$$

(3)

Obtained

$$X_{max} = \frac{F/k}{2\zeta} \qquad (\zeta small, \text{ and } X_{max} \text{ occurs in } v/\omega=1)$$

(4)

and

$$X_P = \frac{X_{max}}{\sqrt{2}} = \frac{F/k}{\sqrt{2}.2\zeta} = \frac{F/k}{\sqrt{\left[1-\left(\frac{P}{\omega}\right)^2\right]^2 + \left[2\zeta\frac{P}{\omega}\right]^2}}$$

(5)

Because

$$\left[1-\left(\frac{P}{\omega}\right)^2\right]^2 + \left[2\zeta\frac{P}{\omega}\right]^2 = 8\zeta^2$$

(6)

and

$$\left(\frac{P}{\omega}\right)^2 = (1-2\zeta^2) \pm 2\zeta\sqrt{1-\zeta^2}$$

(7)

if ζ small then

$$\frac{P_2^2 - P_1^2}{\omega^2} = 4\zeta\sqrt{1-\zeta^2}$$

(8)

and

$$\frac{P_2^2 - P_1^2}{\omega^2} = \left(\frac{P_2-P_1}{\omega}\right)\left(\frac{P_2+P_1}{\omega}\right) = 2\left(\frac{P_2-P_1}{\omega}\right)$$

(9)

because $(P_2+P_1)/\omega = 2$, with resonance respond assumption is symmetric for the value ζ small

Thus $\frac{P_2 - P_1}{\omega} = 2\zeta = \frac{\Delta\omega}{\omega} = \frac{1}{Q}$

(10)

In which $\Delta\omega$ is bandwidth frequency in half power point.

Table 1. Factors Lose Some of the Material Structure

Material	Loss factor
Aluminum-pure	0.00002 – 0.002
Aluminum alloy-dural	0.0004 – 0.001
Steel	0.001 – 0.008
Lead	0.008 – 0.014
Cast iron	0.003 – 0.03
Manganese copper alloy	0.05 – 0.1
Rubber-natural	0.1 – 0.3
Rubber-hard	1.0
Glass	0.0006 – 0.002
Concrete	0.01 – 0.06

Damping on the Connection

When personal damping in small material structure, most of the attenuation that occurs in the actual structure, more than 90% occurred in the connection structure.

The amount of damping in the connection get less attention to be examined and controlled because of the very complexity of dissipation energy mechanism in the joint. Construction in wet and dry connection is the construction on a different stiffness than a joined structure. If construction of the connection is weaker and tends to be flexible, the sliding mechanism on the connection that contributes energy dissipation absorption is occurred. Sliding mechanism can be minimized by strengthening the structure, but the connection structure absorbs less energy dissipation. Scale factor of friction, μ, in sliding mechanism plays the important role in damping power in connection structure.

The oretical formulation of the damping that occurs in connection is difficult to make due the variation of μ, but generally, the appearance of the friction factor on the interface connection depends on the type material on the contact area and the proportion of the normal force on the interface. The addition of friction damping by adding a special damping is not required but the optimization laying connections is more needed. The cost will be cheap and easy way to in crease personal damping by optimizing damping in the joint. In wet connection, the addition of damping on the connection when it cracks caused by friction reinforcement and concrete in open areas due to cracking.

Damping Mechanism in Reinforced Concrete

Material damping of reinforced concrete on the elitist (no melting in the reinforcement) due to bending loads shows the specific forms of structural elements at the crack. When the structural elements have not been cracked yet, the attenuation mechanism happened is pure flexible damping, viscous damping, material reinforced concrete. Damping mechanism will change when there is an additional stress caused by the external forces which

cause cracks structural elements. After cracking mechanism occurs not only viscous mechanisms but also friction mechanisms, friction damping. The increased cracking causes the less flexible damping. Frictional damping that occurs at the crack area tends to remain in size.
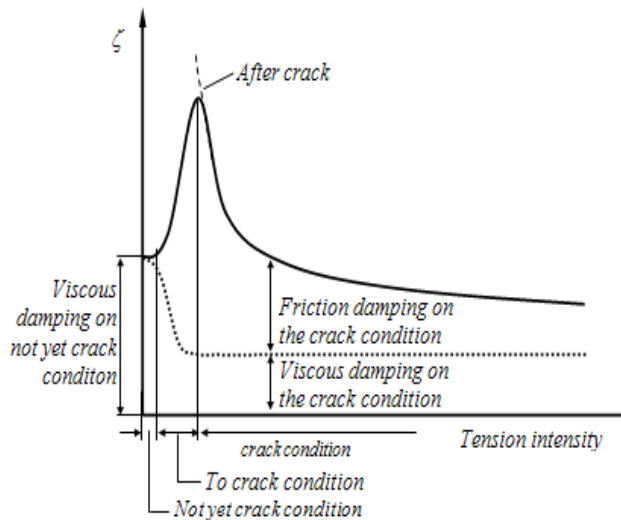

Figure-8.Damping ratio in some circumstances according Mahrenholtz and Bachman (1995).

According Mahrenholtz and Bachman(1995), the damping depends on the strength of the stress intensity(Figure-8). Damping ratio of reinforced concrete in several different circumstances the stress intensity. The addition of the stress intensity resulting in cracking an damping ratio will in crease. At the end of fractured condition but still with a lows tress intensity, the damping ratio is still high, at two or three times of the price than the state has not been cracked. In line with the increase in stress intensity, the damping ratio decreases and will reach a priceless than the state before it cracked.

Damping behaviour of reinforced concrete due to bending load sin some circumstance scan be divided into two states(Figure-8). The first is on not yet crack state occurred in the concrete that almost purely viscous damping. The second is the state of existing cracks that occur in two places, namely the area has not been cracked concrete compressive and tensile regions that have been cracked. At the press area that has not cracked the existing damping is almost purely viscous damping and in the area ofthe cracked tensile frictional damping occurs between there in forcing bars in concrete(Figure-9). With two kinds of damping(viscous and friction) that occurs in the mechanism of reinforced concrete beams that have cracked due to bending loads, therefore the damping material form of the model can be described as shown in Figure-10.
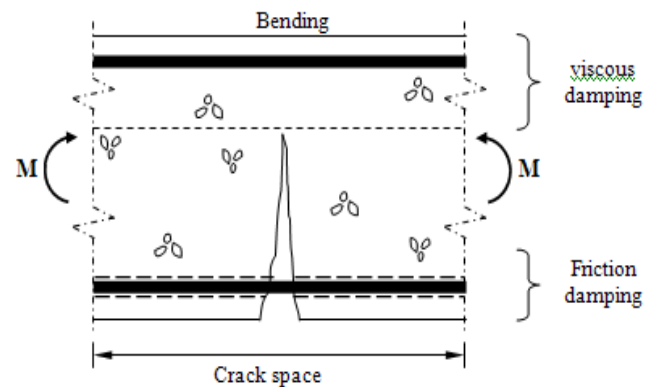
Picture-9.cracking in reinforced concrete flexible elements according to Mahrenholtz and Bachman(1995).
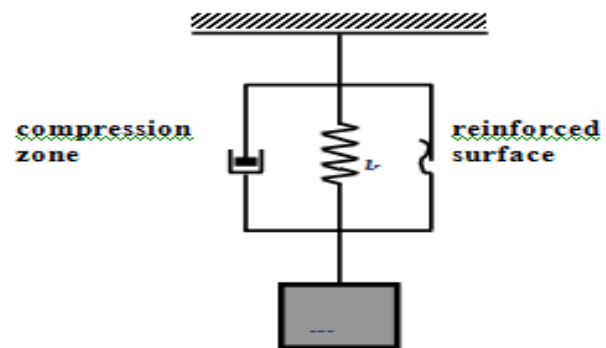

Figure-10. Model damping material of reinforced concrete

Dynamic test

There are two types of test to measure the vibration. The first is the measured response force or vibration during operation structure and the second one is a test where the structure is vibrated by the excitation force magnitude is known and known as the 'Capital Testing'. The base of the testing modal is the natural frequency, resonance pattern attenuation structure. There are several reasons why the modal testing is used in the measurement of vibration of structures. The first is the structural vibration testing is expected to get an accurate price of natural frequencies. The second is the resonance pattern of structural response to dynamic loads can be used to analyze the existing damping in the structure. And the third is the basic mathematical theory of vibration of the test is good enough.

In the testing of reinforced concrete structural elements with a single excitation point as shown in Figure-11, there are some aspects of the measurement process to obtain the accurate data. The first aspect is the aspect of mechanics which determine the conditions of the laying of the structure and location of the load to be done on the structure. The second is the number of observations transducer according to the load and the response to be measured. And the third aspect is the signal process according to the type of testing.
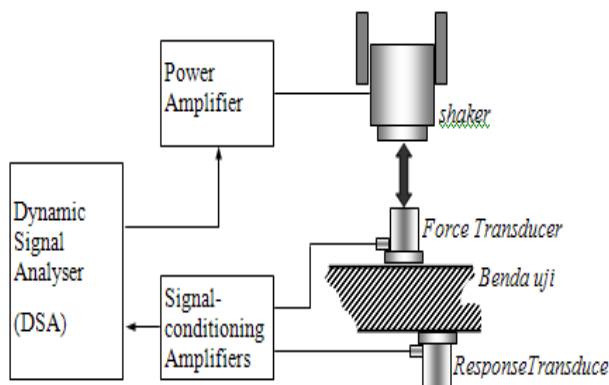
Figure-11.The basic components of testing system

The laying of the test object adapted to the structure function. On testing the structural elements of reinforced concrete, laying of structural elements adapted to structure function. Laying a simple form is laying the foundation of the joints and two rollers at each end of the structural elements. By knowing the structure laying , the system structure can be analyse de it her SDOF or MDOF and structure mode.
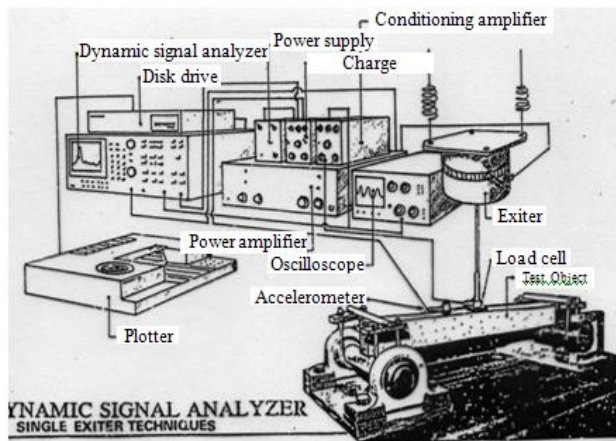

Figure -12.Setup dynamic testing.

The position of Test Objects

In scope of the problem is mentioned that the damping behaviour of reinforced concrete beams which are connected properly or not is the attenuation that occurs in the first mode shape. Specimen used in this study is reinforced concrete structural elements with rectangular cross section of 10 X 18 cm2. Beam placed on two pedestal at each end. Excitation loads in static and dynamic testing placed at mid span (Fig. 7). Pattern due to the load mid span deflection must be equal to the first shape mode pattern and in order to get the results therefore position of the test object at the time of loading is in the smallest cross-sectional inertia.
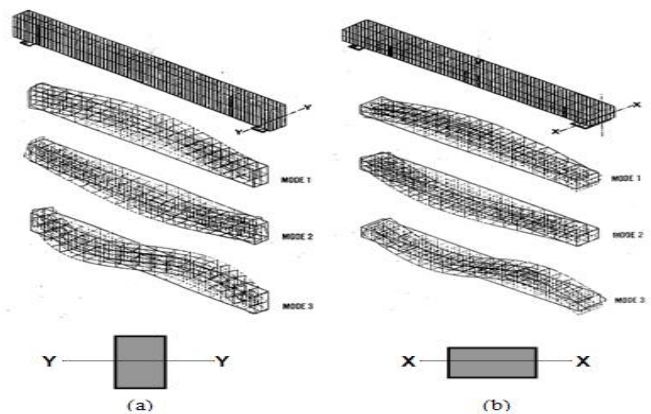

Figure 13.Modeshape1, 2and3 on the modeling of the test object(a) an upright position and(b) sleeping position

The Test Results

In the dynamic testing, reinforced concrete beam is given the excitation force and by using an accelerometer, the structural response can be detected. Structural response at resonance is when the load frequency equal to the natural frequency of the beam, therefore the pattern shows the natural frequency of the resonant structure and magnitude of structural damping. Dynamic testing performed on three conditions, namely when the beam remains elastic condition, the condition of cracking and crumbling condition. Table 2 shows the magnitude of the natural frequency of the beam structure and Table 3 shows the attenuation structure (units per cent showed the ratio of the price elastic).

Table 2.Natural Frequency of the Beam on Elastic Conditions, Cracks and Ultimite.

No	Name of Beam	Elastic	Crack		Ultimit	
		Natural Frequency (Hz)	Natural Frequency (Hz)	Relativity to the elastic	Natural Frequency (Hz)	Relativity to the elastic
1. Beam with two wet connections						
1	BG1	83	67	82%	42	51%
2	BG2	78	75	95%	46	59%
3	BG3	86	74	89%	51	60%
4	BG4	79	74	95%	49	62%
2. Beam with one wet connection						
5	BT1	80	64	79%	49	60%
6	BT2	76	63	82%	44	57%
7	BT3	73	58	79%	45	62%
8	BT4	73	64	88%	52	71%
5. Beam without connection (monolit)						
17	MC1	89	69	73%	41	47%
18	MC2	89	78	89%	48	55%
19	MC3	82	72	88%	46	56%
20	MC4	78	70	90%	40	51%

Table3.Damping Of The Beam Structure On The Condition Of Elastic, Cracked And Ultimit.

No	Name of Beam	Elastic	Crack		Ultimit	
		Damping (%)	Damping (%)	Relativity to the elastic	Damping (%)	Relativity to the elastic
1. Beam with two wet connections						
1	BG1	4,5	5,4	120 %	2,2	49
2	BG2	6,5	5,5	85 %	2,7	42
3	BG3	5,2	5,4	104 %	3,4	65
4	BG4	5,7	6,7	118 %	1,8	32
2. Beam with one wet connection						
5	BT1	5,6	5,2	93 %	3,2	57
6	BT2	5,8	5,2	90 %	3,7	64
7	BT3	4,9	3,5	71 %	2,2	45
8	BT4	4,7	2,8	60 %	2,9	62
5. Beam without connection (monolit)						
17	MC1	6,1	5,0	82 %	3,0	49
18	MC2	6,0	5,3	88 %	4,3	72
19	MC3	5,8	5,2	90 %	4,5	78
20	MC4	5,7	5,5	96 %	3,8	67

Damping

Damping of the beam structure on the two support structures calculated from the response at resonance excitation due to loads that have a frequency equal to the natural frequency of the structure. Method of calculation is done by half power point method. On beam with a wet connection either with two connections or one connection, the damping in the elastic state to state ultimate tends to decrease. On the beam with two wet connections, the decreased damping from elastic condition to ultimate condition was 53%. On beam with a wet connection, damping price reduction from elasctic condition to the ultimate condition was 43%.
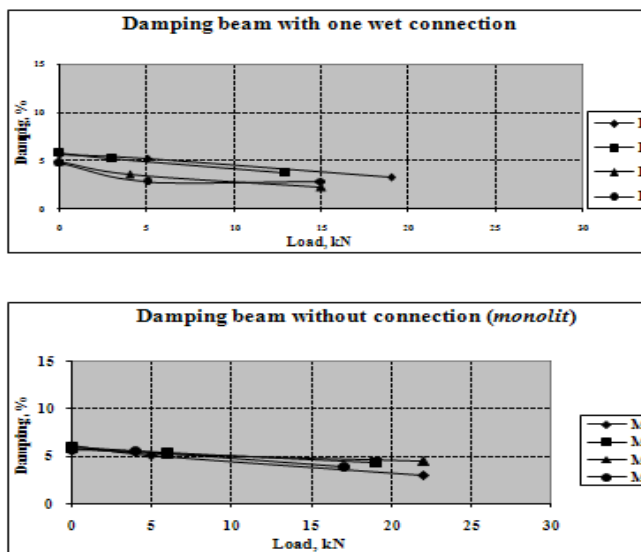

Figure -14.Damping Graphs vs. load for beams with two and one wet and beam connection without connection (monolith).

Conclusion

Before reaching the stage of a tensile crack, the structure got the tensile stress and press on the mid span cross-section due to the load. The addition of tensile stress and the press before reaching cracks weakened the structure and consequently increased the damping of the structure. After cracking, the damping was divided into two parts, the viscous damping in a structure that had not been cracked cross-section and friction damping on the open structure due to cracking. Viscous damping depends on of the beam cross-sectional area that was still intact in the event of cracking. On cracking condition, the beam with a wet connection had the largest average damping as 7.6%, then the beam without a connection was 5.25%, and beam with damping wet connection was 5.0%

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