FORCE DISTRIBUTION OF REINFORCED CONCRETE COUPLING BEAMS WITH DIAGONAL REINFORCEMENT

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Abstrak

The structural behaviour of reinforced concrete couple shear walls is greatly influenced by the behaviour of their coupling beams. The behaviour of the coupling beams themselves depends on the geometry of the beams and the strength characteristics of the concrete and reinforcement. Behaviour characteristic of deformation and mode of failure at coupling beams that happened is the existence of compression area at diagonal direction coming in contact with tip of force, tension area at opposite diagonal direction which will have crack till split at diagonal area compress, and the beam will attain its maximum load carrying capacity when small portion of the concrete in the compression corners crush. Mode of failure that happened is shear failure. The proposed method of analysis of reinforced concrete coupling beams based on the equilibrium of forces of a triangular half of the beam at failure gives a satisfactory prediction of force in the main bars. The distribution of force in the main bars of the beams at failure is showed using the proposed concept, when the diagonal splitting mode of failure occurs, is tensile. The force varies linearly along the span with a smaller value at he tip of the triangular half of the beam to its full capacity at the support. Although it was not possible to compare the force directly with the experimental result, the observed behavior agrees with the proposed concept. The distribution of force in the bars based on the conventional concept of flexural deformation of reinforced concrete coupling beams differs drastically with the actual behavior.

Key words : Coupling beams; CRT Bar ; ductility ; diagonal reinforcement; force distribution

Introduction

Multistory shear walls with openings present a number of problems. If the openings are very small, their effect on the overall stress minor. However, large openings have much more pronounced effect. Opening (windows, doors, and the like) normally occur in regularly spaced vertical rows throughout the height of the wall. So, their must to provide a structure that could be function to transfer the force between the vertical walls. For that purpose, hence provided a beams to connecting the walls. The structural behaviour of reinforced concrete couple shear walls is greatly influenced by the behaviour of their coupling beams. The behaviour of the coupling beams themselves depends on the geometry of the beams and the strength characteristics of the concrete and reinforcement. Many beams with coupling force have been designed as conventional flexure members with stirrups and with some shear resistance allocated to the concrete are oftentimes will inevitably fail specially at diagonal areas, hence for beams with coupling force is recommended that the beams are reinforced with diagonal systems (bi-diagonal reinforcement)

Analysis

Reinforcement Design :

Gravity load effects on these beams are neglected.

It is recommended that in coupling beams of structural walls, the entire seismic design shear and moment should be resisted by diagonal reinforcement in both directions.

Maximal allow shear stress :

$V_{max} = 0{,}1 \cdot l_n \cdot \sqrt{f'_c} \; / \; h$ (MPa)

$V_{max} = 1{,}2 \cdot (l_n / h) \cdot \sqrt{f'_c}$ (psi)

Minimum allow shear stress :

$V_{min} = Q_u / (\phi \cdot b_w \cdot d)$; $\phi = 0{,}85$

If v_{min} > v_{max} , diagonal reinforcement should be used in all coupling beams to resist the entire earthquake-induce shear force.

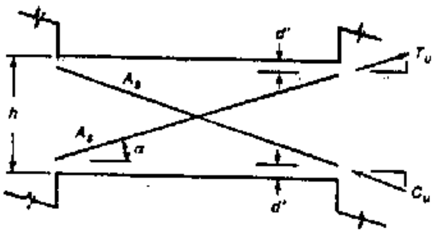


Fig 1. Force direction and notation of coupling beams

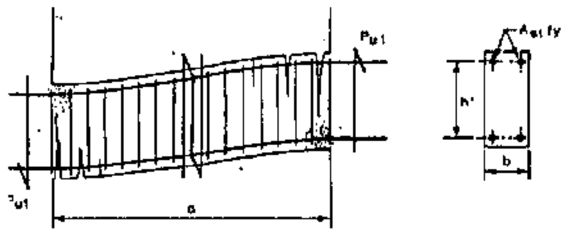


Fig 2. Flexural deformation of beam and force

Fig. 1, from this, it is seen that the diagonal force are :

$C_u = T_u = Q / (2.\sin \alpha)$

The area of diagonal steel required is :

$A_{sd} = T_u / (\phi.f_y)$; $\phi = 0,9$

$= Q / (2.\phi.f_y.\sin \alpha)$ (MPa)

Transverse reinforcement area required is :

$$A_{te} = \frac{\sum A_b.f_y}{16.f_{yt}} \cdot \frac{s}{100} \quad \text{(mm)}$$

where, $s \leq 100$ mm

$s \leq 6 . d_b$ (D-diagonal)

$s \leq 24$ x D-sengkang

Development length required is :

$$l_{db} = \frac{1{,}38.A_b.f_y}{c.\sqrt{f'_c}} \quad \text{(mm)}$$

where, $2c_s$ is center-to-center distance between bars in the vertical plane.

The development length of this group of four bars is, however, to be increased by 50%.

$l_d = 1{,}5 \times l_{db}$ (mm)

When transver ties are also used within the wall, the development length may be reduced with :

$$k_{tr} = \frac{A_{tr}.f_{yt}}{10.s}$$

with reduction factor : $\frac{c}{c + k_{tr}}$

and thus,

l_d = reduction factor x 1,5 x l_{db} (mm)

Deformation

The true deformation of the coupling beams is a combination of the flexural and shear deformations. But in any particular case, either flexure or shear will govern. When **flexure** governs, the overall deformation of the beam is still accurately represented by flexure type deformation (**Fig. 2**) and as in **(1)** is reasonably accurate for estimating the ultimate strength of the beam.

$$\mathbf{P_u = \frac{2h}{a} . A_{st} . f_y} \quad (1)$$

Shear Deformation

A pure shear deformation and the actions produced in the beam are shown in **Fig. 3a** and **Fig. 3b**. The pure shear deformation requires both top and bottom surfaces of the beam all along the length to be tension. There is compression along the diagonal AC and tension along BD. An element of the beam near the mid span is subjected to a biaxial compression tension state of stress. The concrete crack when the tensile stress in the concrete along the diagonal BD reached the limiting tensile strength of concrete.

The mode of failure in shear is characterized by the extension of the diagonal crack up to the position of the main reinforcement diagonally opposite and by the crushing in the compression corners (**Fig. 3b**)

When the behavior is governed by shear, the overall deformation of the beam is much more complex. The flexural deformation causing the beam to bend in double curvature, with tension along one-half of the beam changing into compression along the other half on both top and bottom surfaces, conflict with the shear deformation which causes the beam to go into tension on both surfaces along entire length.

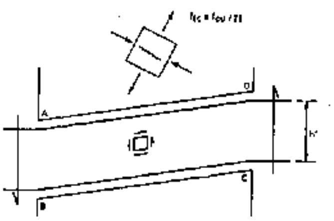
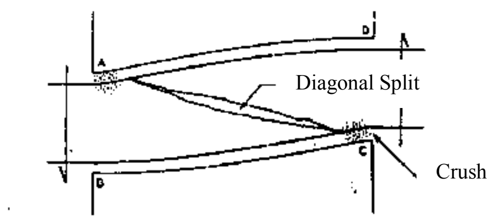


Fig. 3a. Initial stage : element under biaxial stage



Gbr. 3b. Final stage : Diagonal splitting and crushing of concrete

Ductility Deformation

Ductility defines the ability of a structure and selected structural component to deform beyond elastic limits without excessive strength or stiffness degradation (**Paulay-Priestly, 1992**). The most convenient quantity to evaluate the ductility imposed on structure by an earthquake, or the structure's capacity to develop ductility, is displacement. The **displacement ductility** is :

$$\mu_\Delta = \frac{\Delta}{\Delta_y}$$

Where, $\Delta = \Delta_y + \Delta_p$. The yield (Δ_y) and fully plastic (Δ_p) component of the total lateral tip deflection Δ.

Coupling Beams Analysis (N.K. Subedi, 1988)

The analysis of coupling beams subjected to flexural and shear stress actions, and in which the structural behaviour is governed by shear, may be carried out by considering the force system in a triangular half of the beam as shown in **Fig. 4**.

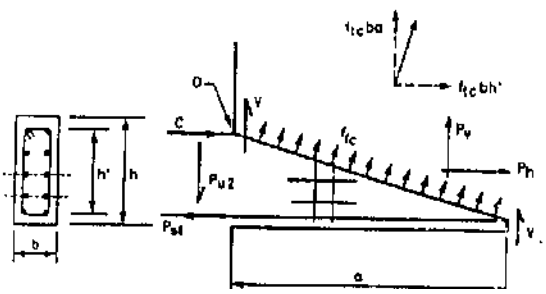


Fig. 4. idealized diagram : equilibrium of triangular half of the beam

The following equation may be written :

Vertical equilibrium :

$$P_u = 2.V + f_{tc}.b.a + P_v \quad (2)$$

Horizontal equilibrium :

$$P_{st} = f_{tc}.b.h' + P_h + C \quad (3)$$

momen about 0 (M=0) :

$$P_{st}h' = V.a + f_{tc}.\frac{b.(h'^2+a^2)}{2} + P_h.\frac{h'}{2} + P_v.\frac{a}{2} \quad (4)$$

From eqns. (2) to (4), the ultimate load for the beam may be expressed as

$$P_u = (f_{tc}.b.h' + 2.C + P_h).\frac{h'}{a} \quad (5)$$

In proposing equation **(5)** the most important criteria for the failure of coupling beams is assumed to be the crushing of the concrete of depth (h-h') / 2 in highly stressed compression corners. The compressive force, $C = 0{,}67.f_{cu}.b.(h-h') / 2$

The quantity $f_{tc}.b.h$ and contribution of P_h depends on whether the web strength is controlled by concrete or by reinforcement.

Control of Web Strength and Contribution of Web Reinforcement

The web reinforcement consists of horizontal web bars placed in the central part of the beam between the top and the bottom main bars and vertical stirrups. The control of web strength and contribution of the web bars depends on the relative capacities of the concrete splitting force and the web reinforcement. The following criteria tests may be applied :

When the web strength I controlled by reinforcement, $P_h = \lambda_1.A_h.f_{sy}$, $P_v = \lambda_2.A_v.f_{sy}$ and f_{tc} will not contribute. Here, $\lambda_1.\lambda_2 = 1$. When the web strength is controlled by concrete, $P_h = A_h.f_s$, $P_v = A_v.f_s$ and f_{tc} will contribute. Here, f_s = modular ratio x f_{tc} and λ_1 and λ_2 are factors which depend on the geometric parameters.

Test	$f_{fc}.b.h' + A_h.f_s$	$f_{tc}.b.a + A_v.f_s$	Web strength is controlled by
(a)	$< A_h.f_{sy}$	$< A_v.f_{sy}$	**reinforcement**
(b)	> or > $A_h.f_{sy}$ or <	> or > $A_v.f_{sy}$ or <	**concrete**

The criteria tests indicate clearly that, for the web reinforcement to be effective, sufficient amount must be provided in both directions, i.e. horizontal and vertical. If sufficient reinforcement is present in one direction only, e.g. closely spaced vertical stirrups but no additional horizontal bars, the effectiveness of the reinforcement will be small. The introduction of factors, λ_1 and λ_2, suggests that, for a better utilization of the web reinforcement must be provided in the same proportion as the components of the concrete splitting force. When the web strength is governed by the reinforcement and also when the proportion of the reinforcement in the horizontal and the vertical directions is in the ratio.

$(f_{tc}.b.h' + A_h.f_s) / (f_{tc}.b.a + A_v.f_s)$

$\lambda_1 = \lambda_2 = 1.$

That represents an efficient use of the web bars.

Contribution of Main Reinforcement

The contribution of the main bars may be examined from equation **(3).** Since the compressive force, C, is assumed to be equal to 0.67 $f_{cu}.b.(h-h')/2$ at failure, P_{st} can calculated. Now, if P_{st} is less than the capacity of the main bars, $A_{st}.f_y$, it is assumed that the main bars will not yield at the failure of the beam. If P_{st} is greater than $A_{st}.f_y$, the main bars will yield at failure.

Force Distribution in Main Bars

It is assumed that the force in the main bars varies linearly from T_o at the tip of the triangular half (**Fig. 4.**) to T_a at the support. For the evaluation of T_o, equation **(2)** is expressed as

$$V = ½ . (P_{u2} – f_{tc} . b.a – P_v) \quad (6)$$

in which P_{u2} is calculated from equation **(5)** and the contribution of the other quantities is obtained as appropriate, i.e. based on whether the control of web strength is by concrete or by reinforcement. Then, referring to **Fig. 4.**, the force in the main bar near the tip of the triangle may be obtained from

$$T_o = \frac{V_a}{h'} \quad (7)$$

the force in the bar at the support, T_a, is evaluated from equation **(3)**, as discussed earlier.

Research Method

This research pertained experimental laboratory research where the parameters used to be based to the theoretical analysis.

The analysis are:

- Theoretical analysis whit using some parameters that relevant to predict the deformation behavior of coupling beams. This analysis will produce the theoretical values.
- Experimental analysis, where the data from analysis theoretical to be treated to the specimens (coupling beams). This analysis will produce the experimental values.

Failure Process.

Deformation that happen on coupling beams in this experiment is a combination of the flexural and shear deformation Behaviour characteristic of deformation and mode of failure at coupling beams that happened is the existence of compression area at diagonal direction coming in contact with tip of force, tension area at opposite diagonal direction which will have crack till split at diagonal area compress, and the beam will attain its maximum load carrying capacity when small portion of the concrete in the compression corners crush

This behaviour requires fresh explanation and may be described as follows (see **Fig. 6**):

(i). At early stage of loading, the beam starts to deform in common flexural type behaviour (**Fig. 6a**). At this stage, the beam has double curvature with a line of contraflexure at the center of the span. A line of contraflexure is defined as the line passing through the points of contraflexure of the horizontal layers of the beam. But soon after, when the shear force is large enough to initiate a diagonal crack, the double curvature (flexure) behaviour changes.

(ii). As the crack opens up because of increasing diagonal tension compression effect, the outer concave part of the curvature on both top and bottom surfaces of the beam pushes outward gradually. This is equivalent to a shift in the position of the points of contraflexure in reinforcement from their original position at the center towards the supports in the opposite direction. It can be visualized from **Fig. 6b** that the line of contraflexure rotates anticlockwise as the diagonal crack in the concrete spreads outwards from the center

(iii). The shift in the position of the point of contraflexure in the reinforcement will stop near the fixed end support where the conflicting deformation required for the bending and shear action cause the reinforcement to kink (**Fig. 6c**). At this stage, the concrete will have cracked most of the way diagonally showing a marked separation near the middle. The reinforcement, both top and bottom, will be in tension along most of its length except near the kink where the local affect will influence the behaviour.

(iv). The beam will attain its maximum load carrying capacity when small portion of the concrete in the compression corner crush, thus marking the failure of the beam (**Fig. 7**).

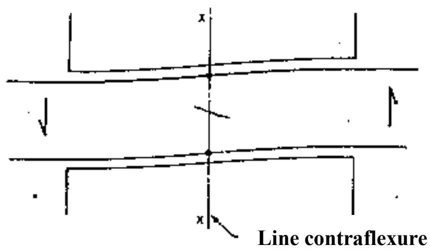


Fig. 6a. Early stage : flexural behaviour

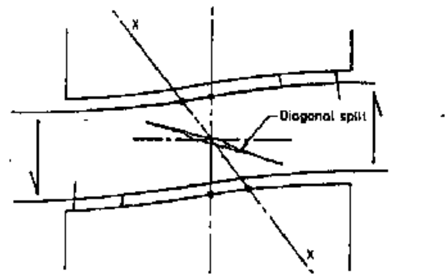
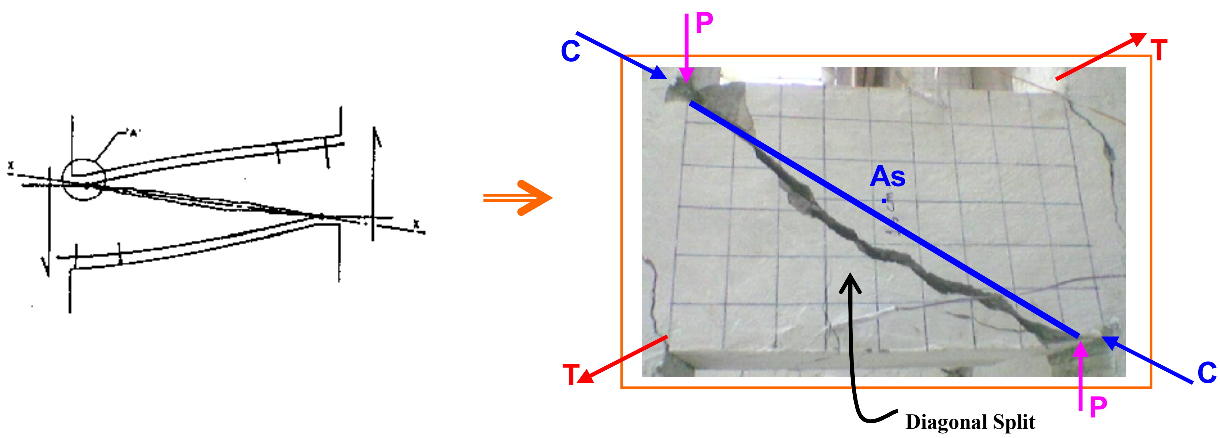


Fig. 6b. Diagonal splitting and rotation of the line of contraflexure

Crack Pattern and Split

The diagonal split wide values of coupling beams with diagonal reinforcement placing (Deform and also of CRT Bar) is 1,35 cm, and the diagonal split wide value of conventional coupling beams is 2,75 cm. from this data proved that coupling beams whit diagonal reinforcement can lessen widely of split up to 50,91% compared to is wide of split at conventional coupling beams.

This result can be enabled to happened because with the existence of diagonal reinforcement addition in one group (four bars) hence will be formed a concrete core that can resist the tension stress at diagonal stress areas. The diagonal stress areas will be contrary direction with diagonal compress areas. But, wide of diagonal split among usage both types of the steel bar do not show differ far.



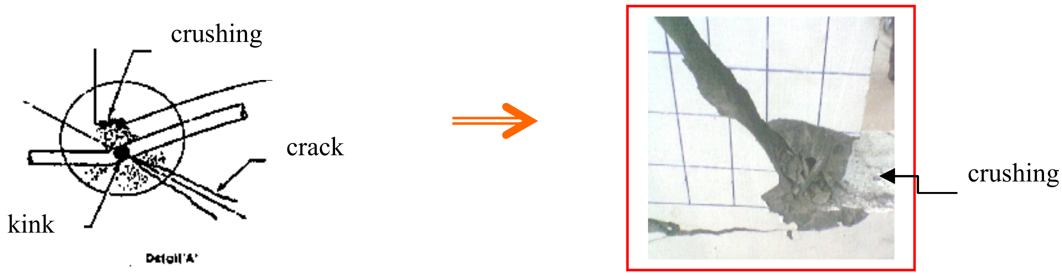
Source : Experiment

Fig. 6c. Final stage at failure : Final deformed shape

Referring to **Table. I**. two values for the ultimate strength, P_{u1} , based on the flexural mode of failure are given. The second row of P_{u1} value were calculate from equation **(1)** in which the flexural strength is based on the capacity of the main reinforcement alone.

The fifth row of P_{u1} values was extracted from equation **(5)**. These values represent the actual strengths based on the total horizontal bars in the cross section. It is clear that the flexural strengths are underestimated in the case of beams with the additional horizontal bars. Therefore, it is reasonable to take into account all the horizontal bars in calculating the flexural strength of the section.

Comparing the theoretical, P_{u1} and P_{u2}. it is evident that in all cases, P_{u1}, is smaller. Hence the predicted mode of failure in all cases is shear or diagonal splitting with the crushing of the concrete at highly stressed compression corners.



Source : Experiment

Fig. 7. Kink area

The experimental observations of the modes of failures agree well with this prediction. The ultimate loads for the beams were predicted using equation **(5)**. The ratios in the last row of **Table 5**. P_u analysis / P_u test, suggest that the predicted values agree well with the test result.

Displacement Ductility

Deflection value measured at the tip area of the beam that opposite with back part area that getting the force (load). Read of deflection use the LVDT. The displacement ductility values is :

$$(\mu_\Delta) = \frac{\Delta_u}{\Delta_y}.$$

Where, μ_Δ = ductility
Δ_u = deflection at ultimate load
Δ_y = deflection at yield load

TABLE I
COMPARISON ANALYSIS OF CONVENTIONAL COUPLING BEAMS BETWEEN EXPERIMENTAL AND THEORETICAL RESULT

Experimental Result (BK)	f_c'	N/mm^2	21,073
	Mode of Failure	Shear, major diagonal crack, concrete and steel stresses seriously disturbed at the compression corners.	
	P_u, experimental	kN	**114,84**
Theoretical Result	f_{cu}	N/mm^2	26,341
	f_{tc}	N/mm^2	1,254
	P_u, flexural failure	kN	217,8410
	P_u, Shear failure	**kN**	**112,1181**
	Predicted mode of failure	Shear, diagonal splitting and crushing of concrete at the compression corners.	
	Ultimate load P_u, analysis	kN	**112,1181**
$\frac{P_u\text{, analysis}}{P_u\text{, experimental}}$	**0,9763**		

Deflection at yield (Δ_y) took at first crack moment. Deflection at ultimate (Δ_u) took if the beams reach maximum load that marked with split moment. Structures response at six specimens shown that the ductility response included in Restricted ductility, because the structure have value of maximum displacement ductility (μ_Δ) in interval 1,5 to 3,5.

The proposed method of analysis, as in **(1) to (5)**, was used to analyze the beams. In each case the first step was establish whether the web strength was controlled by concrete or by reinforcement. It is obvious that, in beams with only vertical stirrups, the control of web strength is by concrete, beams 1 is example. In beam 2 the proportion of web horizontal reinforcement is small, and the overall control is governed by concrete. In beam 3, 4, 5 & 6, there is adequate reinforcement in both the horizontal and vertical direction. Therefore the web strength is controlled by the reinforcement. The proportions are such that the strengths due to reinforcement are similar to those due to concrete. Therefore, in practice either can controlled the web strength.

Force Distribution in Main Bars

The distribution of force in the main bars of the beams at failure is shown in **Fig. 8.** using he proposed concept, the force in the main bars, when the diagonal splitting mode of failure occurs, is tensile. The force varies linearly along the span with a smaller value at he tip of the triangular half of the beam to its full capacity at the support. Although it was not possible to compare the force directly with the experimental result, the observed behavior agrees with the proposed concept. The distribution of force in the bars based on the conventional concept of flexural deformation of reinforced concrete coupling beams differs drastically with the actual behavior (**Fig. 8**).

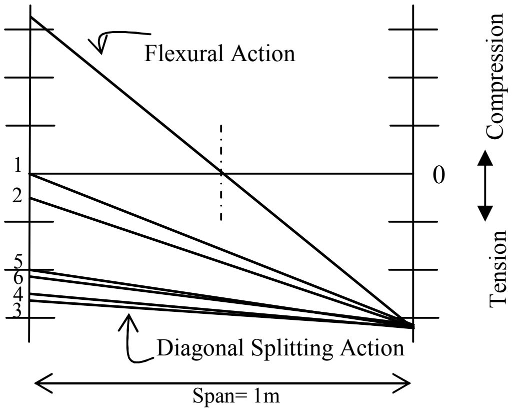


Fig. 8. Theoretical distribution of forces in the main bars

Conclution

Behaviour characteristic of deformation and mode of failure at coupling beams that happened is the existence of compression area at diagonal direction coming in contact with tip of force, tension area at opposite diagonal direction which will have crack till split at diagonal area compress, and the beam will attain its maximum load carrying capacity when small portion of the concrete in the compression corners crush. Mode of failure that happened is shear failure. Ratio between P_u (analysis of N.K. Subedi method) with P_u (experiment) is equal to 0,98, this number indicate that analysis with N.K. Subedi method can be used to predict the value and behaviour of ductility at coupling beams. The distribution of force in the bars based on the conventional concept of flexural deformation of reinforced concrete coupling beams differs drastically with the actual behavior . The proposed method of analysis of reinforced concrete coupling beams based on the equilibrium of forces of a triangular half of the beam at failure gives a satisfactory prediction of force in the main bars.

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