EFFICIENCY OF THE SPIKE SHEAR KEY INTERFACE FOR U-SHAPE PERMANENT FORMWORK

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ABSTRACT

The construction industry is witnessing numerous innovations aimed at improving construction site efficiency. One such innovation is the utilization of precast permanent formwork for structures, which helps reduce project time and costs. In Thailand, U-shaped permanent formwork for beam structures typically features a smooth interface. This poses no issues for ground beams, as the force of gravity prevents slippage between the inner concrete and the smooth formwork surface. However, when using such formwork for beams in multi-story buildings, the smooth interface on the inner surface becomes problematic over time. This poses a potential danger in the future.

For solving this problem, researchers have developed a U-shaped permanent formwork solution by incorporating a shear key in the form of a spike within the inner surface. This spike interface is intended to mitigate the aforementioned issues associated with smooth interfaces. The objective of this study is to observe and compare the efficiency, shear capacity, and cracking behavior of three types of beams: reinforced concrete beams (RC-ref beam), beams constructed using smooth inner surface U-shaped permanent formwork (ES beam), and beams constructed using spike inner surface U-shaped permanent formwork (EK beam). The study involves forming the formwork using mortar and conducting experiments to evaluate the shear capacities and deformation, specifically comparing the efficiency of the EK beam against the ES beam and the RC-ref beam, with a focus on the impact of the shear key.

The results of this research will provide insights into the superiority of the EK beam in terms of shear capacities and deformation, owing to the inclusion of the shear key.

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CHAPTER 1
INTRODUCTION

1.1 Background and problem significance

Permanent formwork is a structural element that is used to contain the placed concrete, mold it to the required dimensions and remain in place for the life of the structure. Participating in permanent formwork makes some predetermined contribution to the strength of the structure. Non-participating permanent formwork makes no strength contribution but may provide additional benefits such as improved durability, finish, or insulation properties.

Permanent formworks are part of the permanent structure of the building. The main advantages are that they save time and labor as there is no need to dismantle the formwork. They reduce costs and save time by

· Reducing the skill level needed on site.

· Increasing the potential for standardization and repetition.

· Permitting off-site fabrication in factory conditions followed by scheduled and appropriate deliveries.

· Speeding up erection times, particularly in building works.

· Eliminating the need to strike formwork and falsework.

· Allowing early access for following or concurrent operations.

· Eliminating the program limitations of reuse of formwork.

The use of permanent formwork can reduce construction and maintenance costs, shorten construction time, and improve safety by reducing hazards during construction. It also reduces construction waste generation during construction.

Maintenance costs are reduced by:

· Improving curing of concrete and reducing shrinkage cracking.

· Ensuring adequate cover to the reinforcement and providing associated benefits such as increased resistance to chloride ingress and carbonation, where appropriate.

· In many instances improving the durability of the structure.

· Providing the decorative finish required.

In the construction contractors prefer to use precast structure especially in permanent formwork because it is saving more money, time and labor, there is no need to dismantle the formwork but when the contractor using the precast formwork it will have strength limitation and position to install.

We have noticed the problem of some company that using only the smooth surface of permanent formwork and less amount of steel, it can be cause of accident that it can collapse anytime because of the debonding and the strength of the permanent formwork. The product of the that company can use only the ground floor only because it has floor to support it but for our permanent formwork can be use in both ground floor and the second floor or above because we improve it by increasing the amount of the steel bars and increasing the biding force.

1.2 Objectives

- To reduce the construction time and cost.

- To create new products for the market instead.

- To improve the texture of the permanent formwork to revise the original product that have less strength

- To extend innovation and technology to follow the market demands

1.3 Area of study

1.3.1. Study and testing the surface of precast between smooth interface and spike interface

1.3.2. Analyze Property of Permanent formwork

Study properties

- Compressive Strength (28 days)

- Density

- Load test and beam cracking behavior

- Maximum shear strength

1.3.3 Permanent formwork and RC Beam for testing

- RC Cage 15x20x150 cm (4DB12, ⦰RB9 @30 cm)
- 4-point load setting for testing and cracking behavior of beam

1.4 Procedure

1. Find the best texture of permanent formwork.
2. Make a specimen of each texture.
3. Load test of all specimens.
4. Analyze and conclude the result of research.

1.5 Expected Benefits

1. For understanding the difference between smooth and spike texture.
2. Find the best efficiency texture of the precast permanent formwork.
3. Find the best surface of precast permanent formwork.
4. Produce new innovations that are stronger than the original into the market.
5. Steel reinforced of spike inner-surface U-shape permanent formwork (EK beam) is stronger than smooth inner-surface U-shape permanent formwork (ES beam)

CHAPTER 2

LITERATURE REVIEW

In this chapter, concepts and theories related to this research are discussed. Explain the difference between smooth texture and spike texture and being processed into permanent formwork of reinforced concrete beams and designing an experiment for testing and studying beam erosion.

2.1 Maximum shear stress theory

This theory states that material failure will take place when the maximum shear stress brought on by combined stresses will equal or be greater than the obtained shear stress value at yield in a uniaxial tensile test. From Parasher A equation [5]

Suppose in a uniaxial test, the principal stresses are:

$$\sigma_1 = S_y \tag{3.1}$$

$$\sigma_2 = 0 \tag{3.2}$$

$$\sigma_3 = 0 \tag{3.3}$$

where σ_1, σ_2, σ_3 = maximum normal stress a body can withstand at a certain point; S_y = yield strength.

The shear strength at yielding is:

$$S_{sy} = \frac{(\sigma_1 - \sigma_2)}{2} = \frac{S_y}{2} \tag{3.4}$$

or

$$S_{sy} = \frac{(\sigma_1 - \sigma_3)}{2} = \frac{S_y}{2} \tag{3.5}$$

For a **homogenous, isotropic, ductile material** with two or three-dimensional static stress, to identify and compute for σ_1, σ_2, σ_3 and the maximum shear stress, τ_{max}:

$$\tau_{max} = \frac{(\sigma_1 - \sigma_2)}{2} \tag{3.6}$$

According to the maximum shear stress theory, we can then compare the maximum shear stress to the failure criterion:

$$\tau_{max} \leq S_{sy} \tag{3.7}$$

And therefore, the factor of safety can be given by:

$$N = \frac{S_{sy}}{\tau_{max}} \tag{3.8}$$

1.) Choose an approximate value of the amount of tensile reinforcing steel. and the amount of compression steel reinforcement.

$$\rho = \frac{A_s}{bd} \tag{3.9}$$

$$\rho' = \frac{A_s'}{bd'} \tag{3.10}$$

By ρ is the amount of tensile steel reinforcement.

ρ' is the amount of compressive reinforcement steel.

A_s is cross-sectional area of tensile reinforcement steel. (cm^2)

A_s' is cross-sectional area of the compressive reinforced steel. (cm^2)

b is beam width. (cm)

d is the distance from the outermost edge of the compression to the center of tensile reinforcement steel. (cm)

d' is the distance from the outermost edge of the compressive to the center of tensile reinforcement steel. (cm)

2.) Checking the value of ρ to not exceed $0.75\bar{\rho}_b$ and not less than the lowest value allowed in equation (3.11)

$$\rho_{min} \leq \rho \leq \rho_{max} \tag{3.11}$$

When

$$\rho_{min} = \frac{14}{f_y} \tag{3.12}$$

$$\rho_{max} = 0.75\bar{\rho}_b \tag{3.13}$$

$$\bar{\rho}_b = 0.85\beta_1\left(\frac{f_c'}{f_y}\right)\left(\frac{6120}{6120+f_y}\right) \tag{3.14}$$

$$\beta_1 = 0.85 - 0.05\left(\frac{f_c'-280}{70}\right), f_c' = 380\ kg/cm^2 \tag{3.15}$$

By ρ is amount of tensile steel reinforcement.

ρ_{max} is maximum allowable tensile strength of reinforce steel.

ρ_{min} is minimum allowable tensile strength of reinforce steel.

$\bar{\rho}_b$ is amount of reinforced steel at equilibrium stress with tensile steel only.

f_c' is the maximum compressive strength of concrete. (kg/cm^2)

f_y is yield strength of reinforce steel. (kg/cm^2)

3.) Check the yield of the compressive reinforce steel because the reinforce steel will be yield (follow 3.16)

$$\rho - \rho' \geq 0.85\beta_1\left(\frac{f_c'd'}{f_yd}\right)\left(\frac{6120}{6120-f_y}\right) \tag{3.16}$$

When the reinforcing steel does not yield, use

$$f_s' = 6120\left[1 - \frac{0.85\beta_1 f_c' d'}{(\rho-\rho')f_y d}\right] \quad (3.17)$$

When the compression steel reinforcement yields, use

$$f_s' = f_y \quad (3.18)$$

By f_s' is the strength of compressive steel (kg/cm^2)

4.) Check the amount of reinforced steel which must meet the conditions. 3.19 in case of having reinforce compressive beam.

$$\rho \leq 0.75\bar{\rho}_b + \rho' \frac{f_s'}{f_y} \quad (3.19)$$

5.) Check and calculate the receiving moment by receiving moment have to more than or equal the necessary receiving moment according to equations 3.20 and 3.21.

$$\emptyset M_n \geq M_u \quad (3.20)$$

$$M_n = \left(A_s f_y - A_s' f_s'\right)\left(d - \frac{a}{2}\right) + A_s' f_s'(d - d') \quad (3.21)$$

When $$a = \frac{A_s f_y - A_s' f_s'}{0.85 f_c' b} \quad (3.22)$$

By M_n is resistance of specified moment (kg-m)

M_u is desired strength of the moment (kg-m)

$\emptyset$ is the power reduction factor is 0.90 (for compressive strength)

a is Depth of distribution of compression unit of rectangular box (cm)

6.) Convert the moment resistance power (M_n) to the four-point load power (P), loading test to compare the result according to Equation 3.23.

$$P = \left(\frac{W_g L^2}{8}\right)\frac{3}{L} \quad (3.23)$$

By P is resistance of specified moment (kg)

w_g is static loading weight of beam (kg/m)

L is effective length of beam (m)

Summarize the design of beams in group 1 using the amount of reinforced steel for tensile strength of 2.05 percent of the beams, Group 2 and 3 use 2.51 percent of the amount of tensile reinforcement steel.

2.1.1 Shear-resistant beam design

Design of reinforced concrete shear beams follow (วสท. 1008-38) standard where the design shear strength ≥ shear strength follows the eq (3.24)

$$\emptyset V_n \geq V_u \quad (3.24)$$

When

$$V_n = V_c + V_s \quad (3.25)$$

So

$$\emptyset(V_c + V_s) \geq V_u \quad (3.26)$$

By V_n is nominal shear strength (kg)

V_u is required shear strength (kg)

V_c is shear strength of concrete (kg

V_s is shear strength of shear reinforcement (kg)

$\emptyset$ is the reduction factor is 0.85 (for shear) in terms of shear strength required for all building can be found from the above equation where the desired shear strength is equal to V_u for weights acting vertically and power reduction factor (∅) is 0.85

วสท. (011008-21)Standard has formulated an equation to be used in the design of the building that resist shearing force suitable for computer-aided design or research use by specifying the receiving power of shearing strength of concrete V_c and shear strength of stirrup V_s as equations 3.27 and 3.28.

$$V_c = 0.53\sqrt{f_c'}bd \quad (3.27)$$

$$V_s = \frac{A_v f_{sy} d}{S}(sin \propto + cos \propto) \quad (3.28)$$

when using stirrup in vertically ($\propto = 90°$)

$$V_s = \frac{A_v f_{sy} d}{S} \quad (3.29)$$

By b is beam width (cm)

d is the distance from the edge of the compression force to the center of gravity of the steel reinforcement tensile strength (cm)

f_{sy} is yield strength of shear reinforcement $(kg/cm)^2$

A_v is cross-sectional area of shear reinforced steel (take twice the area of one reinforcing steel) $(cm)^2$

S is distance between shear reinforcement steel (cm)

Requirements of design the reinforced concrete beams for shear resistance

1.) Shear reinforcement is not required when

$$V_u \leq 0.50\emptyset V_c \quad (3.30)$$

2.) Minimum shear reinforcement is required except for the floor when

$$0.5\emptyset V_c < V_u \leq \emptyset V_c \qquad (3.31)$$

The reinforcement of shear reinforcement will follow standard (ว.ส.ท)

$$\emptyset V_s = min\emptyset V_s = \emptyset 3.5bd \qquad (3.32)$$

Distance of maximum shearing reinforcement

$$max\ S \leq \frac{d}{2} \leq 60cm \qquad (3.33)$$

3.) Shear steel shall be reinforced according to (2) without exempting the floor when

$$\emptyset V_c < V_u \leq [\emptyset V_c + min\emptyset V_s] \qquad (3.34)$$

4.) Need shear reinforcement when

$$[\emptyset V_c + min\emptyset V_S] < V_u \leq \left[\emptyset V_c + 1.1\emptyset\sqrt{f_c'}bd\right] \qquad (3.35)$$

Shear reinforcement

$$\emptyset V_s = V_u - \emptyset V_c \qquad (3.36)$$

$$\emptyset V_s = \frac{\emptyset A_v f_{sy} d}{S} \qquad (3.37)$$

$$max\ S \leq \frac{d}{2} \leq 60cm \qquad (3.38)$$

5.) Shear reinforcement must be reinforced when

$$\left[\emptyset V_c + 1.1\emptyset\sqrt{f_c'}bd\right] < V_u \leq \left[\emptyset V_c + 2.1\emptyset\sqrt{f_c'}bf\right] \qquad (3.39)$$

Reinforcement of shear steel according to (วสท.) standard

$$\emptyset V_s = V_u - \emptyset V_c \qquad (3.40)$$

$$\emptyset V_s = \frac{\emptyset A_v f_{sy} d}{S} \qquad (3.41)$$

$$max\ S \leq \frac{d}{4} \leq 30cm \qquad (3.42)$$

Summarize the design of beams group 1-3 using the distance between the shear reinforcement steel 120, 300 and 500 mm.

2.1.2 Calculation of the deflection of the beam

วสท.(011008-21)Standard Determine the deflection distance according to the elastic theory as follows:

1.) Calculate the position of the neutral axis (**kd**) from Equation 3.32.

$$k = \left[\sqrt{2n\left(\rho + \frac{2\rho' d'}{d}\right) n^2(\rho + 2\rho')^2}\right] - n(\rho + 2\rho') \qquad (3.32)$$

when $$n = E_s/E_c \qquad (3.43)$$

by k is the distance from the top surface of the beam to the axial line (cm)

n is modulus ratio

ρ is amount of tensile steel reinforcement

ρ' is amount of steel reinforcement for compressive strength

d is the distance from the edge of the compression to the center gravity of the steel reinforcement tensile strength (cm)

d' is the distance from the edge of the compression to the center gravity of the steel reinforcement compressive strength (cm)

E_c is elasticity modulus of concrete $(\mathrm{kg/cm})^2$

E_s is elastic modulus of reinforcing steel $(\mathrm{kg/cm})^2$

2.) Find the Effective Inertia Moment (I_e) following the eq (3.34)

$$I_e = \left(\frac{M_{cr}}{M_a}\right)^3 I_g + \left[1 - \left(\frac{M_{cr}}{M_a}\right)^3\right] I_{cr} \tag{3.44}$$

When

$$M_{cr} = \frac{f_r I_g}{(h/2)} \tag{3.45}$$

$$f_r = 2.0\sqrt{f_c'} \tag{3.46}$$

$$I_{g=\frac{1}{12}bh^3} \tag{3.47}$$

$$I_{cr} = \frac{b(kd)^3}{3} + nA_s(d-kd)^2 + (n-1)A_s'(kd-d)^3 \tag{3.48}$$

By I_e is effective inertia moment (cm^4)

M_{cr} is moment of rupture (kg-m)

M_a is the maximum bending moment acting on the considered cross-section (kg-m)

I_g is inertia moment of all cross-sections (cm^4)

I_{cr} is inertia moment of fracture section (cm^4)

f_r is rupture modulus of concrete

h is beam depth (cm)

b is beam width (cm)

3.) The middle bending of beam is the sum of the deflection distances due to static loading of reinforced concrete beams spreading with deflection point due to the 4-point load that shown in equation (3.49).

$$\Delta = \frac{5}{384}\frac{w_g L^4}{E_c I} + \frac{23}{648}\frac{PL^3}{E_c I} \tag{3.49}$$

By I is inertia moment of beam cross-section (cm^4)

$I = I_g$ is the moment that less than the fracture moment of the beam (cm^4)

$I = I_e$ is the moment being greater than the fracture moment of the beam

Δ is bending distance at the center of the length of the beam (cm)

W_g is static loading weight of beam (kg/m)

2.2 Reinforced concrete beam behavior under load

if a reinforced concrete beam subjected to a small transverse load that increases gradually. under transverse load, the beam will go through three stages before the collapse. These stages are uncracked concrete stage, concrete crack-elastic stresses stage and beam failure-ultimate stage.

- **Uncracked concrete stage:** at the beginning of loading and when the load is less than the modulus of rupture (is the bending stress in which the beam starts to crack). In this stage, the beam will resist compression stress and tensile stress with no cracks. beam in figure 1 will be subjected to compression on top and tension in the bottom. From TeamCivil. [6]

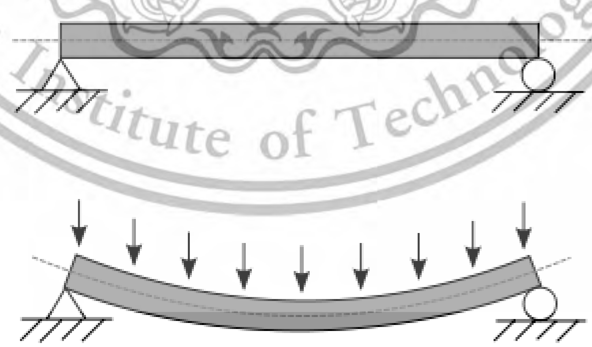

Figure 1: uncracked concrete stage and loading.

- **The concrete cracked elastic stress stage:** once the load is more than the modulus of rapture. the beam will start to crack in the tension zone (bottom of the beam). as the load increase cracks will spread up near the neutral axis. and the neutral axis will begin to move up. concrete will crack in the location which the stress exceeds the modulus of rapture. Or in other words where the moment exceeds the cracking moment is the moment at which the tensile stress is equal to the modulus of rupture). In this stage, concrete will not be able to resist tension anymore. reinforcing steel will resist tensile stress. This stage will continue as long as the compressive stress in top of the beam is less than half of concrete compressive stress fc' and tensile stress in steel is less than yielding stress. in this stage, concrete stress will vary linearly as shown in figure 2. usually for a beam under service-load applied moment will exceed the cracking moment. the compressive stress will be less than 0.5fc'. Therefore, concrete will crack under service load and steel will resist tensile stress.

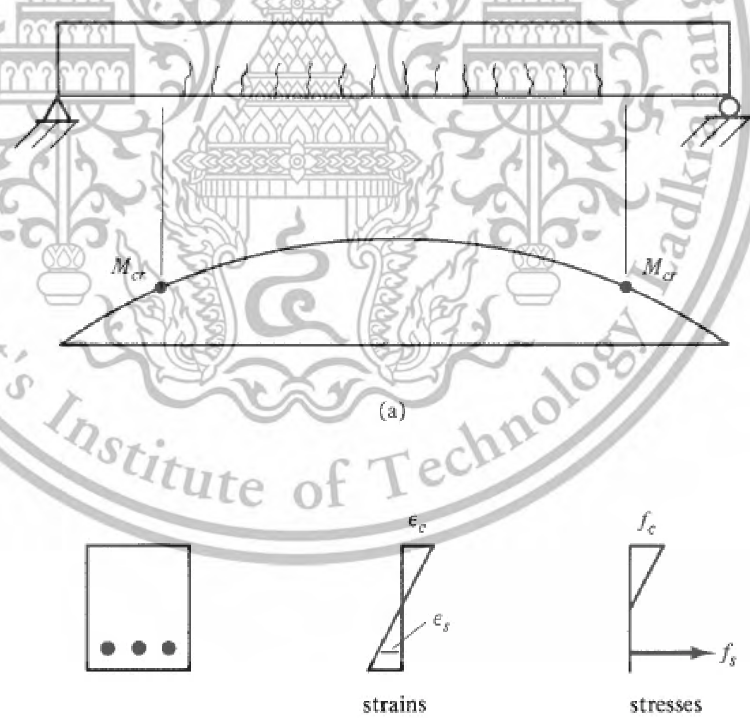

Figure 2: concrete cracked elastic stress stage.

- **Beam failure-ultimate strength stage:** as the load increases and the compressive stress is more than $0.5f_c'$. cracks will increase and move upward. similarly, the neutral axis will move upward. at this stage, steel will yield, and the concrete compressive stress will change from a straight line to as shown in figure 3. Diagram in figure 4 illustrating the relation between curvature θ and moment. where θ is the angle change of beam section over a certain length θ = ϵ / y. where ϵ is the strain of beam fiber at distance y. from the diagram, for the first stage and when the applied moment is less than M_{cr} we can notice that strain is small, and the curve is vertical. when the applied moment exceeds M_{cr}, the slope of curve decreases, and the strain increased. in this stage, beam stiffness is less than the initial stage. the strain will increase sharply when the reinforcing steel yielded as shown in the diagram below. the beam will not fail suddenly when the steel yielded. the beam will be able to carry a small amount of moment before failure as shown in the diagram.

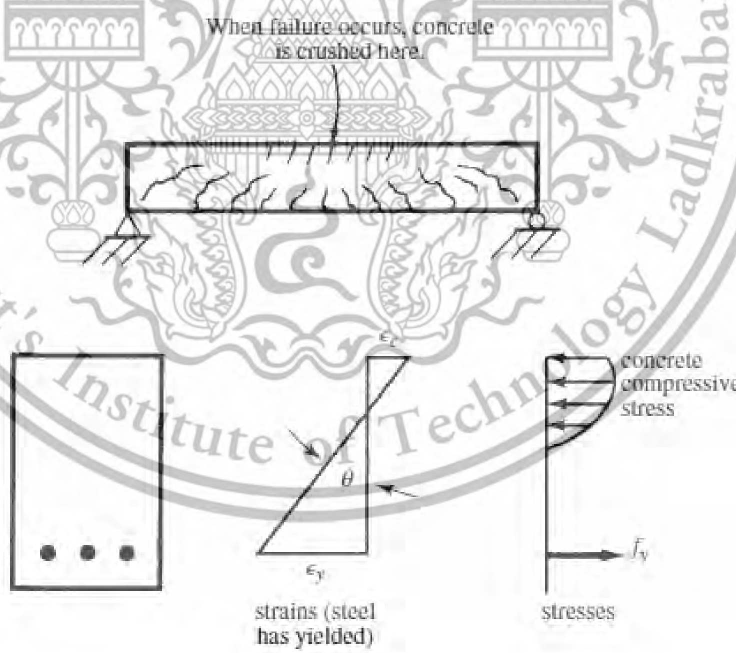

Figure 3: concrete compressive stress changing stage.

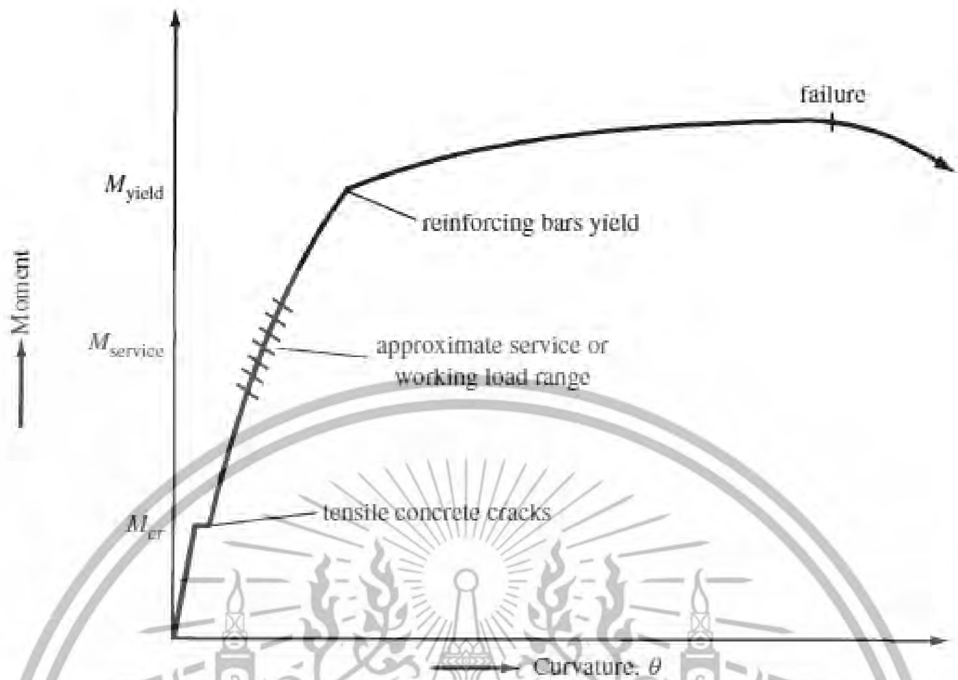

Figure 4: The diagram of relation between curvature θ and moment

Size Name	Mass(Kg/m)	Deviation(Mass/m)	
		Average Percentage	Each Steel Percentage
RB6	0.222	±5	±10.0
RB9	0.499	±3.5	±6.0
RB12	0.888	±3.5	±6.0
DB12	0.888	±5	±6.0
DB16	1.578	±5	±6.0
DB20	2.466	±4	5
DB22	2.984	4	±5
DB25	3.853	4	±5
DB28	4.834	±4	±5
DB32	6.313	±3.5	±4

Table 1 : Tolerance of Mass per meter

Steel Type	Symbol	Resist tensile strength at yield point	Resisting the pulling force at the pin	Flexible in length 5 times of diameter
Round Steel Bar	SR24	≥ 2,400 ksc ≥ 235 Mpa	≥ 3,900 ksc ≥ 385 MPa	≥ 21%
Deformed Bar	SD30	≥ 3,000 ksc ≥ 295 Mpa	≥ 4,900 ksc ≥ 480 Mpa	≥ 17%
	SD40	≥4,000 ksc ≥ 390 Mpa	≥ 5,700 ksc ≥ 560 Mpa	≥ 15%
	SD50	≥ 5,000 ksc ≥ 490 Mpa	≥ 6,300 ksc ≥ 620 Mpa	≥ 13%

Table 2 : Mechanical properties of rebar

2.3 Review of related research

From searching for information there has not been any research that has studied the gutter steel reinforce concrete but have similar researches, including Yip, Teng, Ting and Hu (1999) studied the strength of reinforced concrete beams width 250 mm, depth 450 mm (effective depth 425 mm), length 4000 mm reinforcing steel pull along beam length 5ϕ 22 mm (1900 mm2) and I-shaped steel, cross-section 317 mm×165 mm, embedded at the supporting point of both beams by varying the length of the implant, I shape 4 value that is 425, 638, 850 and 1063 mm(Length increasing by 0.5 for each times of depth of the beam) and varying the distance between shear reinforced steel (size ϕ 8mm) 2 value 200 mm and 350 mm found that

1. The beam fails at the inner end of the I-shaped steel. which is diagonal shear failure by the beam with the distance between 350 mm that resist shear force will be able to support lower loads than beams with distances between reinforcing steel to receive shear stress 200 mm.

2. Shear stress reinforced concrete beams with I-shaped steel supports will be equivalent to reference reinforced concrete beams.

3. At the failure point of the beam with the I-shaped steel embedded in the support it was found that at the tip of I-shaped steel is a critical point as shown in Figure 5

4. Embedding distance of I-shaped cross-section steel at twice the length of the depth effectiveness (l 2.0d) e = will be suitable for shearing and the holding force of the beam because it is the position where the beam can bear the maximum load as shown in Figure 6

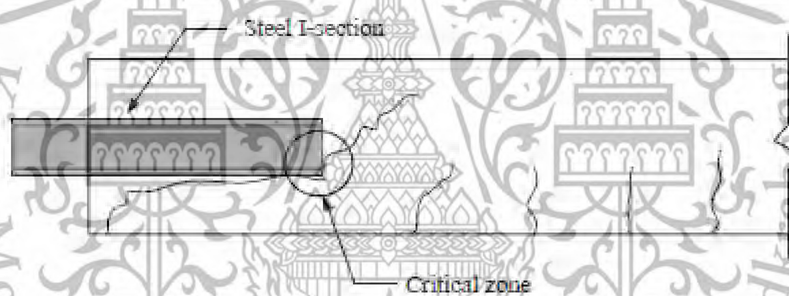

Figure 5 : Failure characteristics of precast reinforced concrete beams with I-shaped steel embedded in the support. [10]

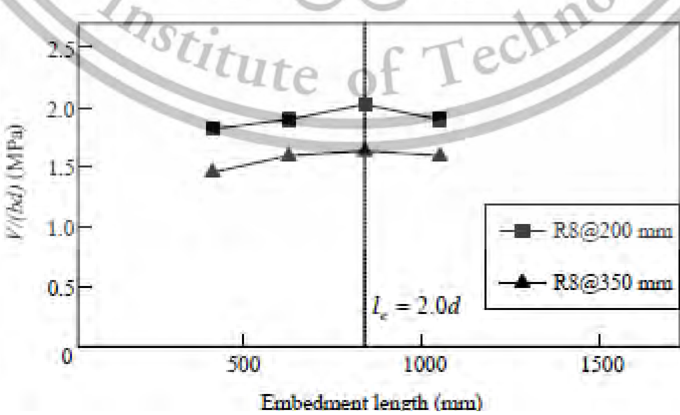

Figure 6 : The relationship between shear strength and I-bar embedding distance [10]

กรรณ และสิทธิชัย (2548) has studied the transverse loading behavior and failure permanent formwork beam compared to concrete beams reinforced steel(follow the standard ว.ส.ท. by using the stable weight). The test specimen used in the study was a beam with a cross section of 175 mm wide and 350 mm deep and the distance between the support points was 4.00 m. Under the four-point load, it was found that.

1. Load bearing behavior of partially prestressed concrete beams is three straight lines but the load bearing behavior of precast reinforced concrete beams in two straight lines as shown in Figure2.3, In the first section, the precast concrete beam partially prestressed its stiffness is about 60% higher than the prefabricated reinforced concrete beams.

2. At the usage (at deflection equal to L/240) In some parts of precast concrete beam can bearing more force than prefabricated reinforce concrete beams about 12-16% and maximum load capacity (at deflection equal to L/100) of partially prestressed concrete beams is greater than reinforced concrete beams about 31-36%.

3. Failures of these two types of beams are similar, that is flexural failure where some prestressed concrete beams crack more frequently and smaller than prefabricated reinforced concrete beams as shown in Figure 7

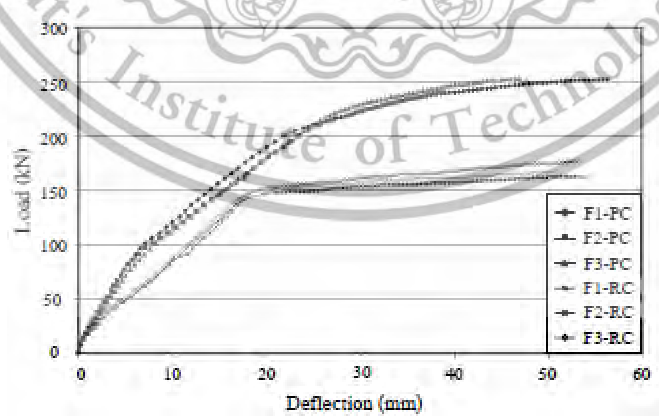

Figure 7 : Relationship between force and deflection of concrete beam [10]

Thosuwan และManachaichan (2001) has studied and compared the process duration and cost of construction during construction by using precast concrete member and cast-in-place. The study has determined the conditions.

Events have the same characteristics, such as the weight of the load, cross-sectional dimensions of building for comparing between these 2 methods. Construction of reinforce concrete beams will take less time than precast beam about 27%, Prefabricated slabs take time 53% less than precast slabs, Precast concrete walls take less time than reinforce concrete walls about 478%, Normal slab take time less than precast slab about 38% and Concrete wall will have less price than reinforce concrete walls about 94%.

From the research mentioned above, it can be concluded that it is possible to use reinforced concrete beams that have gutter steel inside the support more than using precast reinforced concrete beams in the construction. Therefore, it is suitable to research checking the behavior including failure of reinforce concrete beam that have gutter steel inside in the supporting point to continue develop these reinforce concrete beams.

2.4 Reinforced concrete beams

Reinforced concrete beams are part of the building which is horizontal with the main reinforcement is arranged along the length of the beam to support or resist the bending moment caused by vertical load such as the weight spread from the wall, weight spread from the floor slab or point weights, e.g., from alley beams, etc. In addition, there may be shear reinforcement in the beams that can't resist, this is due to the weight of the applied load force always producing bending moment and shear force. In some cases, the beam may resist the torsion moment also when the load is not acting through the shear center it causes of having some force inside the beams such as flexural force, torsion force and shear force or sometime will have axial force.

2.4.1 Bending moment behavior

All concrete beams are inefficient in bending strength due to their tensile strength of the concrete is lower than the compression very much. Therefore, all concrete beams will fail with the lower load, so the compressive strength is not used fully. For this reason, reinforcing steel is used in the parts of receive the tension near the outermost surface of the tension side by having some covering to prevent the effect of fire and corrosion of steel reinforcement. Therefore, most of the pulling forces in reinforced concrete beams are resisted by reinforced steel while concrete is used to resist compressive forces, the combination of both materials will occur only when there is no sliding moment between these two materials by using high bonding strength deformed steel.

As the loading on the beam mounts up from 0 until beam failure, beams will act differently following the load of the beams, The beams that have less load than the tensile unit in the concrete have not yet reached the modulus of rupture. The total cross-section of the concrete will help to resist the moment at the lower surface of the cross section is subjected to tension and the upper surface of the cross section is subjected to compressive strength, at this condition the stress in the concrete is negligible and is directly proportional to the stress distribution of force units and stresses in concrete and reinforcing steel across the cross section depth as shown in Figure

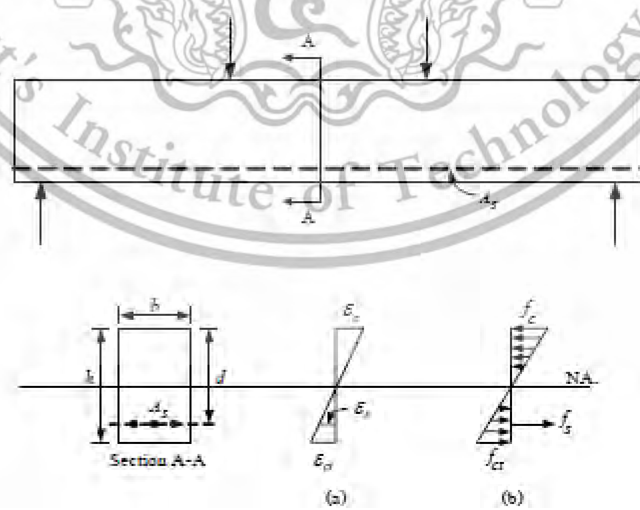

Figure 8 : Rectangular cross-section beam under load in linear elastic range [10]

When the load acting on the beam is mount up until the tensile is increasing to the tensile strength of concrete at the lower surface of cross section area of concrete will cracking due to traction force and rapidly expanding upwards when the force is continuously increasing by crack pattern as shown in Figure 9

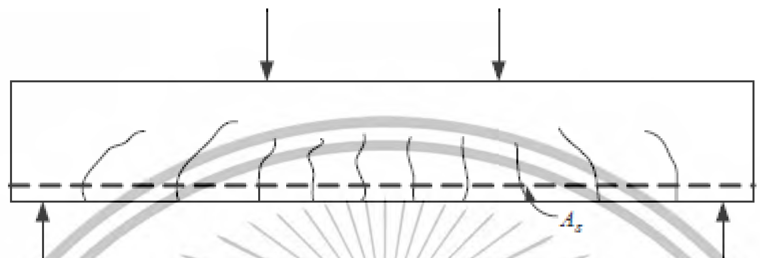

Figure 9 : crack pattern due to the tensile unit [10]

For well-designed beams, the crack width under the service load is very small, in which the cross-section is cracked as in Figure 2.6. Concrete in the cracked area will not be able to withstand tension, so reinforcing steel acts as a load bearing at lower load. If the unit of compressive strength in the concrete does not exceed 0.5f'c force and stress unit are still directly proportional to each other, Force distribution and cross-sectional stress fracture as Figure 10. When the load and stress still mount up disproportionately directly to each other As shown in Figure 10

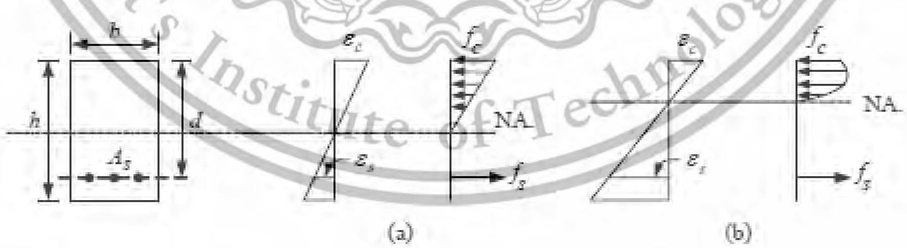

Figure 10 : force distribution and the stress at the fractured cross-section [10]

Until when the reinforced concrete beams reached the failure, Which the failure of the reinforce beams have 2 forms that is yielding failure and crushing are called tension failure and another failure is the concrete was crushed at compression point by the unit of force in the tensile reinforcement has not yet reached the yield point that called compression failure. When considering this failure and compare to amount of steel that in the beams can be classified into 2 types that is

1. Under-reinforced concrete beam with lower amount of tensile reinforcing steel ratio at equilibrium condition that have moderately reinforced, reinforce in beam will always traction until the yield point ($\varepsilon s = \varepsilon y$) as shown in the Figure11. While the distribution of the compressive units in the concrete is not directly proportional to each other. The bending moment causing the steel to yield is called the yielding moment when adding more load. The acting moment will increase causing the reinforcing steel to stretch more while the tensile strength in the reinforcement ($T = A_s \times f_y$) that are constant value and at that time the compressive strength in the concrete must be equal to the tensile strength in the reinforcement according to the principle of equilibrium force but the area of compressive strength of concrete is reduced. due to the neutron axis moving upward thus making the compression unit in concrete increase and the stress of the concrete was increased. Therefore, the distribution of the compressive unit in concrete is no longer proportional to the strain value. The cracks that appear will become wider causing the stiffness of the reinforced concrete beams that decreasing. so, the beams will be bending more order. Which was the pre warning that the beams will fail but if still increasing the weight of the load. The portion of concrete that is above the axial axis is crushed that the distribution of the compressive units. The concrete in the pre-failure will fail like parabolic, as shown in Figure 11.

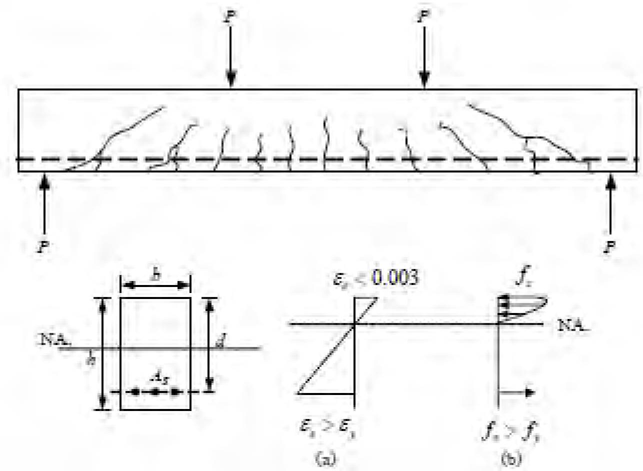

Figure 11 : Failure characteristics due to the amount of tensile reinforcement [10]

2. Over-reinforced concrete beam with the amount of tensile reinforcing steel is exceeded, this beam will be crushing failure where the upper surface of the cross-section area of reinforced concrete beam has the highest stress (**ε**c = **ε**u) about 0.003-0.004 mm/mm as shown in Figue12. Before the tensile reinforcement will yield. it means that the unit of maximum tensile strength within the tensile reinforcement has not yet reached the yield point ($f_s < f_y$)as shown in Figure 12. This kind of failure would be immediate failure by no warning so its danger to life and property.

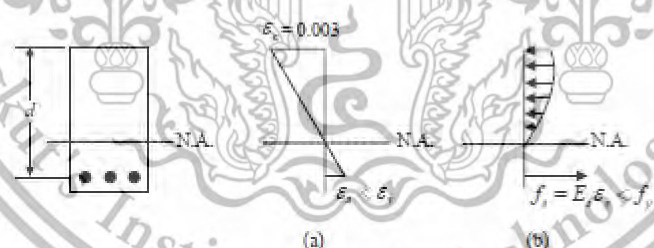

Figure 12 : Distribution of loads and stresses at the failure point. [10]

Figure 13. Shows the relationship between the load and the deflection of the beam in various conditions when reinforce beams is under-reinforced concrete beam and the reinforce will over-reinforced concrete beam from the figure we can see that the bending of the reinforce beam is lower than the ratio that equilibrium condition(Δ2 > Δ1) that mean the reinforce beam will be lower than the ratio of equilibrium condition and will have the ductility is greater than the reinforced beam beyond the ratio at equilibrium. In addition, by the most part, the failure pattern of the tensile reinforced beam is lower than the ratio that equilibrium would have progressive failure behavior and reinforced beams with over-tensile steel than the ratio at which equilibrium will have immediate failure behavior.

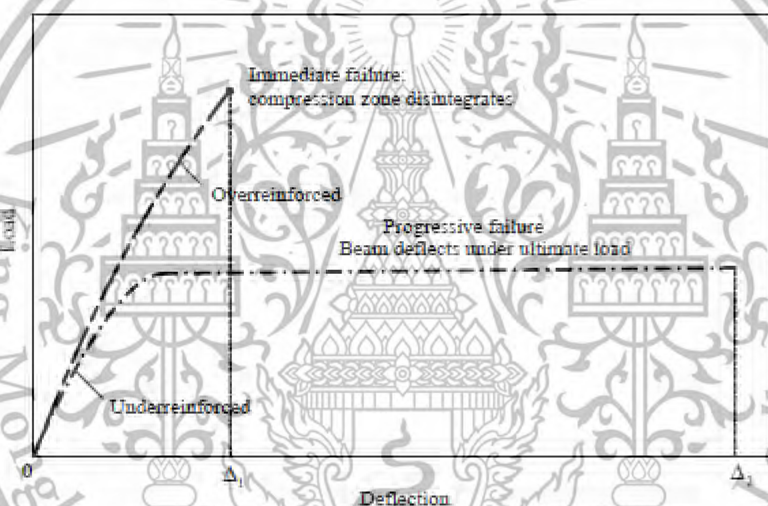

Figure 13 : The relationship between the load and the deflection of the beam. [10]

Therefore, when the tensile strength of the reinforcing beam is equal to the ratio at equilibrium, the failure of reinforced concrete beams are formed in such a way that the reinforcement is pulled to the yield point as the concrete is crushed by concrete with a maximum stress of about 0.003-0.004 mm/mm for safety in condition 4302(ค) follow standard วสท. (011008-21) determine to use the maximum strain equal to 0.003 mm/mm

2.4.2 Shear behavior

The behavior of failure reinforced concrete beams under shear is different from the behavior of failure of reinforced concrete beam under bending force. The failure of reinforce concrete beam that from the shear failure in general it does not occur from the direct shear force but occurs in the diagonal tension because of the action of the shear force and bending moments.

At the end of the beam in which applied large shear force but have less bending moment it will have diagonal cracks appear in the beam. Where the value of the diagonal tensile force is equal to shear units. which the crack has an inclination angle of approximately 45 degrees to the axis of the beam. This type of crack is known as a web shear crack as shown in Figure 14. which will occur with the reinforced concrete beam with having a small width such as I-shape beam. The result from the test showed that in the area that has more shear force will have less bending moment. This shear force makes the concrete cracking that equal to $0.29\sqrt{f_c'}bdkN\left(0.93\sqrt{f_c'}bd\ kg\right)$

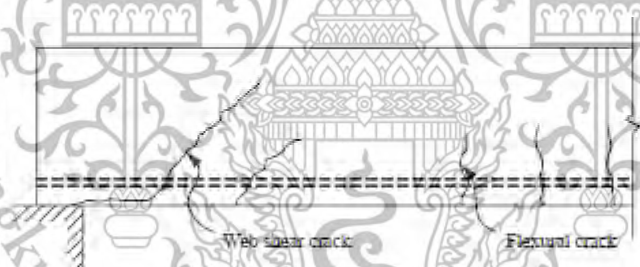

Figure 14: Web shear crack [10]

At the end of the beam in which applied large shear force but have less bending moment it will have diagonal cracks appear in the beam. Where the value of the diagonal tensile force is equal to shear units. which the crack has an inclination angle of approximately 45 degrees to the axis of the beam. This type of crack is known as a web shear crack as shown in Figure 15. which will occur with the reinforced concrete beam with having a small width such as I-shape beam. The result from the test showed that in the area that has more shear force will have less bending moment.

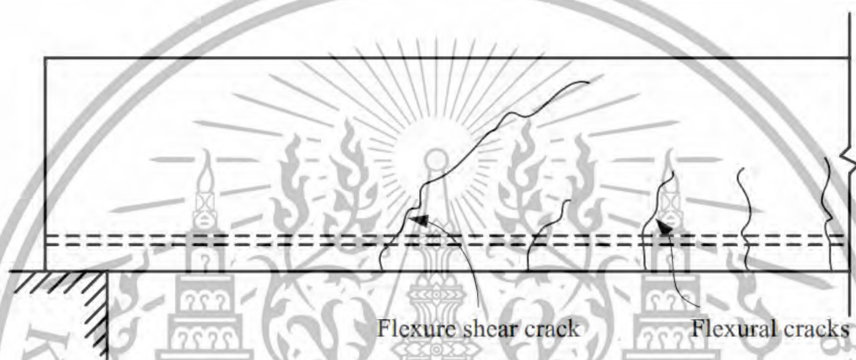

Figure 15: flexural shear crack [10]

The ratio of shear length to depth (a / d) was found from the test as the most influential factor in determining the shear strength. When other factors are constant. The shear capacity will be shown in Figure 16

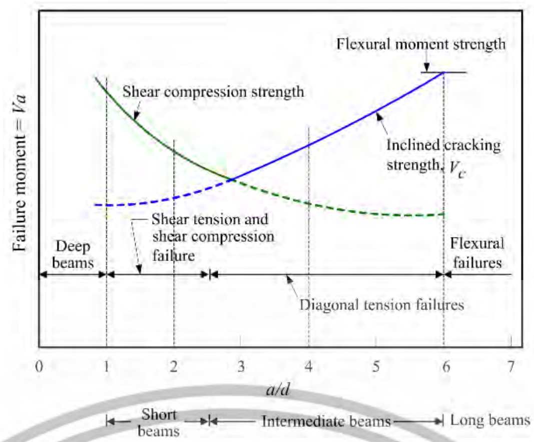

Figure 16: Shear strength at cross-section rectangle beams [10]

From figure16. The failure will be divided into 4 patterns (1) Deep beam (2) Short beam (3) Normal beam (4) Long beam but in this research will focusing in normal and long beam.

Short beam (1 ≤ a / d ≤ 2.5) the failure occurs from the flexural shear cracking and expands to the top side to the area that resist compression force. The failure will occur by (1). anchorage failure in curved steel tensile steel that called shear tension failure. This is due to the destruction of the binding force between the reinforcement and the concrete as shown in Figure 17(a). and (2). By compressive failure in concrete near the compressive surface called shear compression failure, as shown in Figure 17 (b).

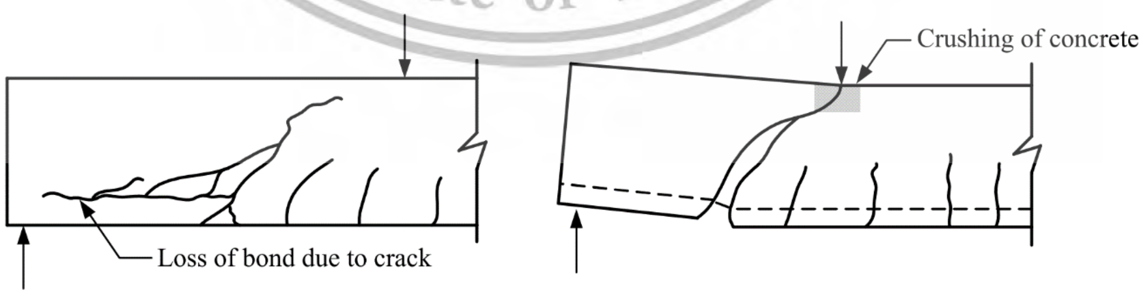

Figure 17: The failure of short beams [10]

Intermediate beam (2.5 ≤ a / d ≤ 6) First it will have bending cracks and shear skew cracks and when the tooth because of increasing the number of cracks, until unable to get the moment from ΔT which rupture causing bending cracks together with shearing cracks as soon as the cracks were sheared. The beam will not be able to distribute the weight anymore. Therefore, the formation of shear cracks is an indicator of the shear strength of this type of beam. The failure is called a diagonal tensile failure (diagonal tension failure) as shown in Figure 18.

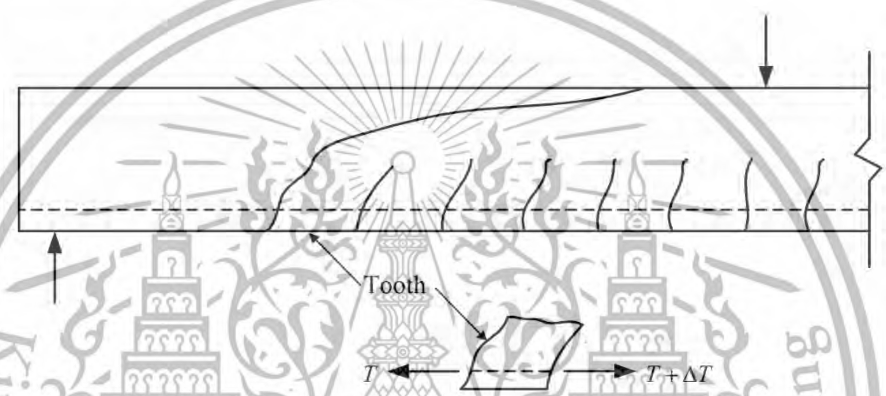

Figure 18: The failure of intermediate beams [10]

Long beam (a / d > 6) The failure of long beam occurred due to the action of bending moment, which is called flexural failure. It begins with the yield of the tensile reinforcing bar and finishes with the compressive crack of the concrete at the cross-section with the greatest bending moment. However, the total power of the beam depends on the magnitude of the bending moment and is not affected by the magnitude of the shear force.

2.4.3 Bending behavior

Figure19 Show the relationship between the load and the deflection of the beam. Reinforced concrete with the amount of tensile reinforced steel under reinforce concrete beam. From the figure, it can be observed that the O-A range is the range which has less load and no cracks in the beam yet. When increasing the load until the moment acting on the beam higher than the value moment of cracking of concrete, small vertical crack will begin to occur at point A which make the stiffness of the beam reduce follow the range of A-B so we can see that the slope of the graph will reducing, the center cracking of the beam at point B will make the strength of the beam reduce, it cause of yielding in tensile reinforcement steel at the center of the beam and the beam will be bending by not to adding the load at point D. In generally the bending of service load will occur at point C. That is the simple bending that occurs immediately but the bending that increases from C to C' that from movement of the concrete will be call long-term deflection.

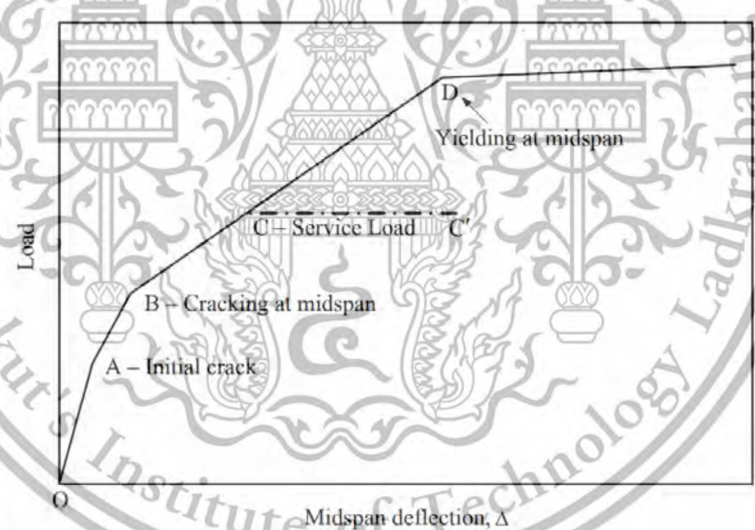

Figure 19: Bending behavior of under-reinforced concrete beam. [10]

2.4.4 General requirements for the design of reinforced concrete beams by strength method.

In 1963, the ACI standard called this method the ultimate strength method design. Later in 1971 the ACI standard provides specifications for design calculations by considering both power and operating conditions. Later in 1983 ACI standard calls for methods calculate the design of reinforced concrete structure using strength design method. The design calculation by this method is to consider the size of the concrete structure and amount of reinforced steel at conditions before failure. It also provided the various internal forces acting on structural parts can be analyzed by using the elastic theory. It must be analyzed thoroughly such as plastic analysis which is quite difficult because it is considered according to inelastic behavior of the structural part before the failure. Reasons for allowing structural analysis based on elastic theory because it was found that the analysis using the elastic theory was sufficiently safe and facilitates design calculations.

Basic assumptions for force design method.

1. The cross-sectional plane is still the same as initial and final of resist the compression force that is stress distribution of the concrete that proportional directly to the distance from the neutral axis.

2. Neglect the tensile strength of the concrete that is in the neutral axis.

3. Bonding between concrete and reinforcement is completely that mean the stress of the reinforcement is equal to the stress of the concrete at the same position.

4. The dispersion of the compressive units in the pre-failure concrete may be of any form that the predicted result of maximum compressive strength of the structure can be close to the result of but the maximum stress of concrete shall not exceed 0.003 mm/mm.

Criteria for design calculation of reinforced concrete structure by strength method.

In conditions where structural parts will fail, the service load multiplied by the load factor, known as the required strength, U the value must not more than the design strength which is the multiplication of the nominal strength of the structure and reduction factor (Ø) that is.

$$\text{load factor service load} \leq \text{reduction factor } (\varnothing) \times \text{nominal strength} \quad (2.1)$$

Required power is the weight that assumes that the structure is going to crack or no longer to resist the force. The value of required power is obtained from working load multiplication with an additional multiplier which the value depends on the type or weight of carrying.

Requirement 4202(a), EIT Standard 1008-38, determines to consider the power desired or devastating weight, e.g.

For buildings that are not subject to wind loads or force from an earthquake

U =1.4DL +1.7LL (ว.ส.ท.) (2.2)

U =1.7DL + 2.0LL (ข้อบัญญัติกรุงเทพมหานคร)

Design power refers to the resistive power of the structural part calculated from the specified power but reduces the value by multiplying by reduction factor. To reducing the resistor is considered reserve resistance of a structure. Which depends on quality control of the work and materials used.

Specification 4203(b) in the EIT 1008-38 standard specifies the value of the reduction factor. (Ø), which have different values (but less than 1.00). Depending on the type of structural part for construction with good control and material quality.

In the condition that the load-bearing structure part is used, Deflection must not be greater than the specified by ACI or EIT standards have given two requirements for controlling the deflection distance model is.

- Controlling the deflection distance using the coordinates of the thickness or thickness ratio coordinates depth to span ratio that is, if the beam or the slab thickness or depth is not less than the given value. (Requirement No. 4205(b), EIT Standard 1008-38). It is assumed that the deflection distance is not much and does not need to calculate the deflection in that section.

- Controlling the deflection distance by specifying the maximum deflection range. (Requirement No. 4205(b), EIT Standard 1008-38) When calculating the bending distance and thickness of the beams or slabs must less than the depth specified.

2.5 Related research

Shear behavior of RC slender beams without stirrups by using precast U-shaped ECC permanent formwork by Rui Zhang, Peng Hu, Xiaohang Zheng, Lianheng Cai, Rui Guo and Dingbang Wei. This study investigated the shear behavior of RC slender beams without shear reinforcements by using precast U-shaped ECC permanent formwork. A total of 10 beams, including 1 RC beam for reference and 9 beams using U-shaped permanent formwork with different thicknesses and interfacial properties were fabricated and tested.

On this related research they use polymer fiber for being the material of U-shape permanent formwork and cast the different interface of formwork beam and compare all beam to find the highest efficiency by shear capacity and cracking behavior to conclude for the best result from all beam. The researchers studied and find that the result of the beam which used shear key is spike have high efficiency for shear carrying capacity and deformation resisting when comparing to all beam. So, the researcher use spike for the research to help this research solve the problem.

Shear Capacity Evaluation of the Recycled Concrete Beam by Qiuwei Yang, Xi Peng, and Yun Sun. Compared with traditional concrete beams, recycled concrete beams are more prone to cracking and shear failure. Generally, shear failure is a brittle failure and its failure consequences are often profoundly serious. Thus, the shear capacity is an important parameter in the design and testing for beam structures. In this work, the computation method and size effect on shear capacity of recycled concrete beams without stirrups are studied.

Reinforced Concrete Design (Working Stress Design: WSD) Assistant Professor S. Damrongsil, Civil engineering, Faculty of Engineering, Rajamangala University of Technology Rattanakosin, The report is a design of reinforced concrete structures by means of working force consisting of Concrete and Reinforcement Structural Analysis and Design The design of reinforced concrete beams resists bending moments and other structures.

Development of CLC block with natural material admixture for heat insulation attribute improvement, Jirapa , Thammasorn and Talarat (2020), KMITL. This research, the application of aerated concrete technology using autoclaved aerated concrete has special characteristics, which is to prevent heat by using special aggregates from waste materials, with natural waste materials, namely coir pith. Coconut, which has basic properties, is a good insulation for construction of residential buildings. Coconut coir pith can reduce the amount of materials in the production of light weight, such as the processing and use of coconut coir pith with heat insulation properties.

NVESTIGATION ON PRECAST REINFORCED CONCRETE BEAMS WITH STEEL C-CHANNEL SECTIONS EMBEDDED AT THE SUPPORT SECTIONS UNDER TRANSVERSE POINT LOADS by Jaksada Thumrongvut (2548). On this related research, they used C-channel steel connect under the beam for additional strength of the beam and for seeing the relationship between stress and strain behavior. The researchers study the plotting diagram from raw data and 4 point load testing by the ASTM standard in Thailand.

CHAPTER 3
METHODOLOGY

This research is the study of texture of permanent formwork for RC beam construction. We try to find the best strength texture.

The Ministry of Interior Regulations (No. 6, B.E. 2527) prescribes a live load (LL) of 200 kg/m^2 and a static load (dead load, DL) of the package. made by brick wall weight 180 kg/m^2 and precast floor weight 240 kg/m^2

Procedure

1. U-shape permanent formwork design
2. Reinforced concrete beam design by ACI318-11 and วสท.011008-21 standard
3. Types of beam design
4. Beam casting procedure
5. Test 4-point normal load setup and procedure for testing

3.1 U-shape permanent formwork design

In Thailand, there is currently no specific act or standard for this composite formwork. Therefore, the researcher utilized the standards for materials used in casting permanent formwork and beams as a basis for design. The objective was to achieve a load capacity that closely matches or is similar to that of a reinforced concrete (RC) beam. When this permanent formwork combines concrete and steel reinforcement and is formed into a beam, the cross-sectional area details are as follows the Fig. 20: the width (b) is 15 cm, the height (h) is 30 cm, and the thickness of the permanent formwork (t) is 2.5 cm.

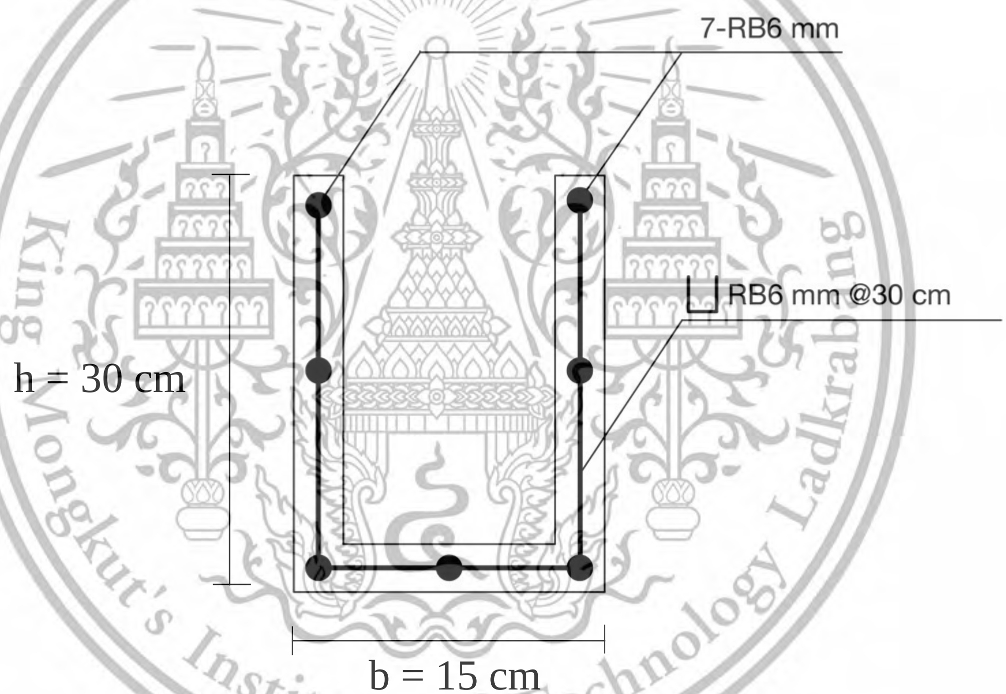

Figure 20 : Cross-section area for permanent formwork design.

3.1.1 Mixed design

The researcher fixed the strength of concrete for RC beam reference is 240 kilogram per area of centimeter and the researcher choose the mixed design of mortar to be material for the permanent formwork combine which steel reinforced case, and we make the experiment for compressive strength testing by cast 3 cube of 40 mm x 40 mm of mortar for each design by using the mix design in Table 3 for achieve a strength value that closely matches the strength of concrete, a comparison can be made. The goal is to obtain a value that is as close as possible to the high strength of concrete.

Mixed design for mortar		
No.	W/C ratio	S/C ratio
1	0.4	0.5
2	0.4	0.5
3	0.4	0.5
4	0.4	1
5	0.4	1
6	0.4	1
7	0.6	0.5
8	0.6	0.5
9	0.6	0.5
10	0.6	1
11	0.6	1
12	0.6	1

Table 3 : Mixed of mortar design for permanent formwork.

Procedure of mortar process

1. Prepare a mold with ASTM C109 standard, size 4 x 4 x 4 cm same as figure 3.2, for casting 3 cubes for each mix design.

Figure 21 : 4-cm Cube ASTM C109 standard mold

2. Prepare and weight the mixture for mortar which is cement, fine sand, and water according to the specified ratio in Table 3 such as with W/C = 0.4 and S/C = 0.5, the researcher will weight, 0.5-kg of cement, 0.25-kg of fine sand and 0.2-kg or 200-mL of water.
3. Pour cement, sand, and water into the concrete mixer by stirring the ingredients together then add water to mixer until all ingredients are combined into one homogeneous mixture.
4. Figure 21, the researcher pours the mixture into the prepared mold 4x4x4 cm, ensuring that the mortar fits well into the mold. Then spread the surface with a trowel and seal the surface with plastic seal to prevent water evaporation.

Figure 22 : Casting concrete specimen cube shape.

5. After 24 hours of age, the pattern was removed. The sample was then incubated in water.
6. On figure 23, when the sample was 28 days old, the specimen was removed from the water surface. Wipe the skin dry to measure the weight at dry skin saturation state. The samples were then dried for 24 hr. and the weight was measured at completely dry condition. and measure the size in both width, length, and height with Vernier caliper and then to test the compressive strength.

Figure 23 : Water curing of all specimens for 28 days.

And the result of this mixed design from our experiment which the researcher calculated and compared is W/C = 0.4 and S/C = 0.5 is ratio with the highest strength from our mix design in Table 3

3.1.2 Procedure of casting the permanent formwork

1. Prepare the steel case for each type of the research beam by using 6-mm round bars. For each formwork, follow the configuration shown in Figure 3.5 and connect them with U-shaped 6-mm round bars spaced at intervals of 30 cm along the length of the specimen beam.
2. Create a U-shaped form using wood as the base for the permanent formwork.
3. Insert the steel case prepared in step 1 into the U-shaped wooden form from step 2.
4. Referencing Figure 24, construct a U-shaped wooden form by reducing its size by 25 mm from the dimensions of the wooden base. This will create a top closure for the steel reinforced case. Additionally, use spacers to maintain a 2.5 cm thickness for the U-shaped covering.

Figure 24 : Steel case in wooden formwork for U-shape permanent formwork.

5. Mixed mortar by using the mixed design from 3.1.1 and pour into the wooden U-shape form for casting the U-shape permanent formwork and take out the wooden formwork in next 3 days.
6. Curing by using water for strength development for 7 days and prepare for casting the beam for the next experiment.

3.1.3 The steel reinforcement's tensile strength

Steel reinforcement will be applied to make compressive strength and tensile training similar. Steel reinforcement is an isotropic material. However, you can test the steel reinforcement's tensile strength on your own. The compressive crates are then tested for tensile strength before tensile strength at the yield point before tensile strength, the maximum elongation, and relaxation of the reinforcement below the tensile strength in order to determine the property values. Mechanical reinforcing steel is used to reinforce reinforced concrete beams.

Testing standard

Thai Industrial Standards Institute (TIS. 20-2543) Standard for steel bars for reinforced concrete: Round bars

Thai Industrial Standards Institute (TIS. 24-2536) Standard for steel bars for reinforced concrete: Deformed bars

Testing sample

1 samples of 6 mm round bar reinforcing steel, RB6 (SR24) for 3 of type for 1 each.

3.2 Reinforced concrete beam by ACI318-11 and วสท.011008-21 standard

In this chapter, the focus is on the behavior of bending moment and shear strength in reinforced concrete beams. It also covers the general requirements for designing reinforced concrete beams according to the standards for reinforced concrete buildings, specifically using the strength method. Furthermore, this section discusses the design of reinforced concrete beams that incorporate gutter steel inside the support points, following the Standard วสท.011008-21. The research analyzes the results of the preliminary beam design, which will be categorized into three groups: the design of reinforced concrete beams to resist shear, bending moments, and calculation of deflection distances in reinforced concrete beams.

3.2.1 Design of beams resisting bending moments

When the amount of reinforcing steel tensile strength (**ρ**) is less than or equal to $0.75\rho_b$ (วสท.011008-21) to determine the flexural moment strength of reinforced concrete beams can be obtained by tensile steel only and make strength of tensile steel reaching the yield point. (Figure25). To facilitate the design process to resist the bending moment.

Consider a reinforced concrete beam. Rectangular cross-section, size **b × h**, reinforced with support steel compressive strength A_s' and reinforcing tensile steel A_s (Figure25). Assuming the distribution of the stress conditions before the beam was broken follow (Figure25). by **c** is the length of the top of the beam to axial amphibious. ε_c is the concrete stress, ε_s' is the stress of the reinforcing steel for compression ε_s is the stress of the tensile reinforcement and the approximate stress distribution of the concrete and steel reinforcement. (Figure25).

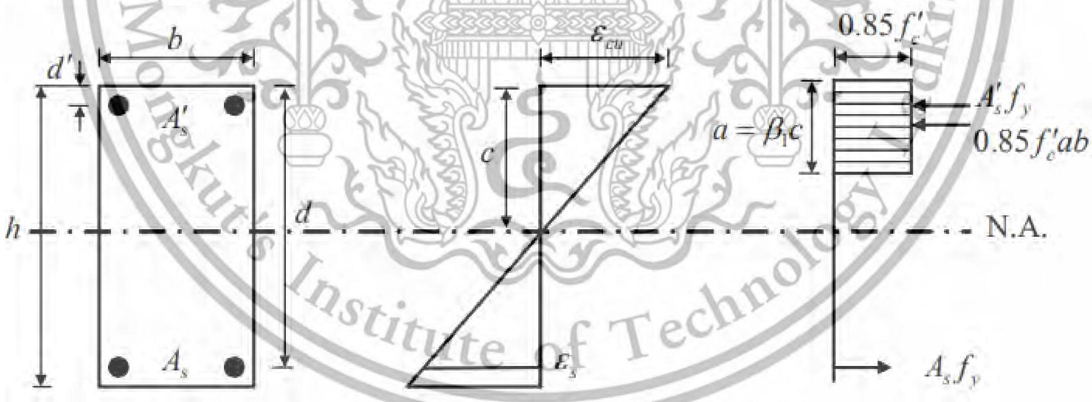

Figure 25: Cross-section area stress and strain

When the beam fails let the side that resist the force fail by reinforcing tensile strength A_s as pulled to the yield point and the concrete will be crushed at a maximum stress of 0.003 mm/mm (วสท.011008-21). compressive steel reinforcement A_s' It may be compressed to the yield point strength, so the compressive strength unit of compressive steel reinforcement is equal to

$f_s' = \varepsilon_s' E_s$ and the maximum of tensile strength in reinforced steel will be equal to strength at the yield point f_y The design of rectangle cross-sectional reinforced concrete beams can be summarized as the beam design simulator from the **NeoRCDesignV5**, the designer of this simulator use ACI318-11 standard for this simulator.

On the figure 26, the beam design simulator must put Length of the beam with 1.50 meters and beam width is 15 centimeters and beam depth are 30 centimeters and give max shear capacity is 4,000 kilograms and bending moment resisting is 1,100 kg-m.

And the result from the simulation design is lower three 12-mm deformed bar and upper two 12-mm deformed bar and 9-mm round bar with 13.75-cm stirrup.

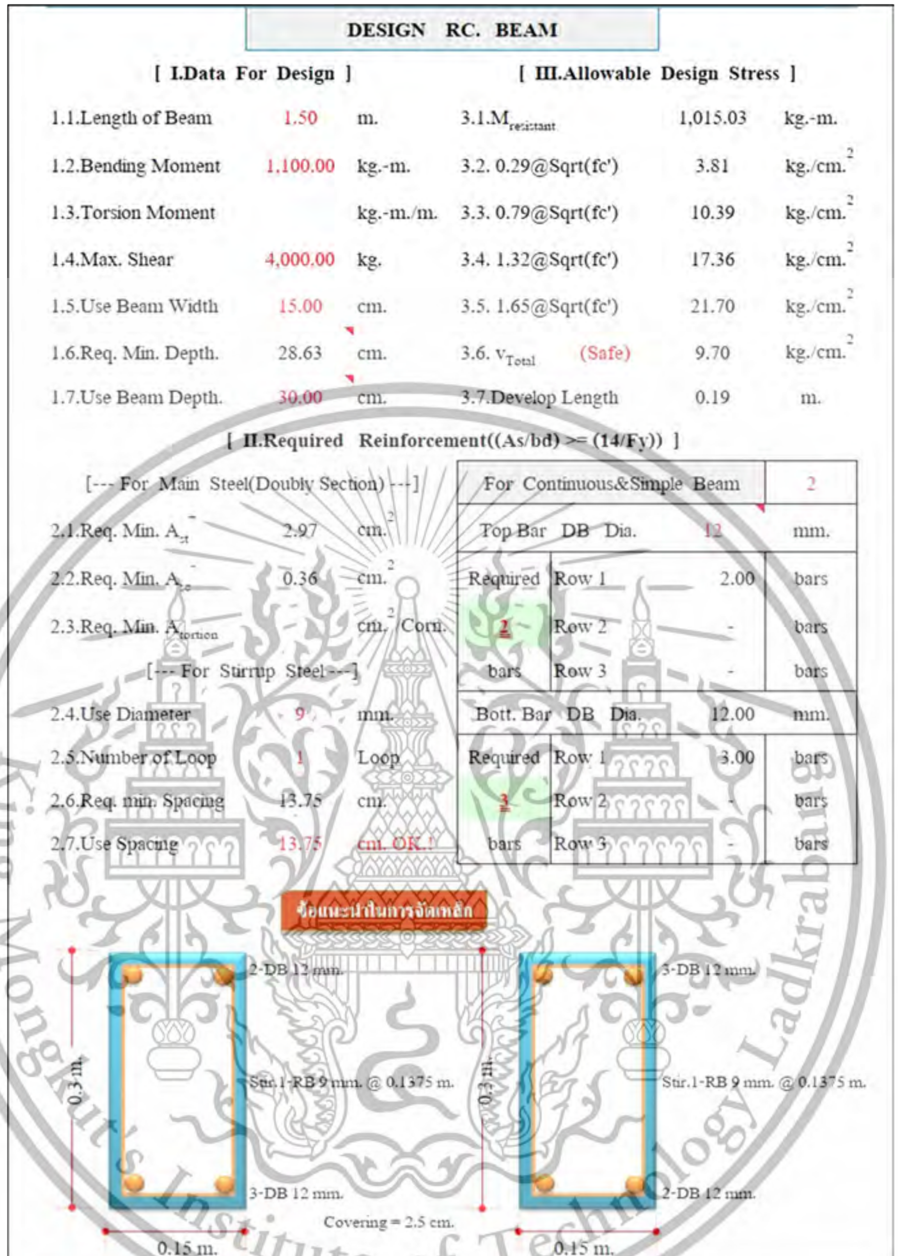

Figure 26 : RC beam design by **NeoRCDesignV5** simulator.

3.2.2 Compressive strength of concrete

Take the sample on concrete that have been built as a beam and bring to find the compressive strength and modulus for testing the reinforce concrete beam.

The expected value is 240 ksc for strength of concrete

Testing standard

Thai Industrial Standards Institute (TIS. 409-2525) Test method for stick resistance concrete (Standard Test Method for Compressive Strength of Concrete Specimens)

Testing sample

A specimen of cubic shape concrete with a size of 0.15 m that has been curing for 28 days, 9 samples. Classify 3 types Including Type A (from RC Beam) ,Type B (from smooth interface) , Type C (from spike interface).

Figure 27 : Cubic of concrete type A

Figure 28 : Cubic of concrete type C

3.2.3 The steel reinforcement's tensile strength

Steel reinforcement will be applied to make compressive strength and tensile training similar. Steel reinforcement is an isotropic material. However, you can test the steel reinforcement's tensile strength on your own. The compressive crates are then tested for tensile strength before tensile strength at the yield point before tensile strength, the maximum elongation, and relaxation of the reinforcement below the tensile strength in order to determine the property values. Mechanical reinforcing steel is used to reinforce reinforced concrete beams.

Testing standard

Thai Industrial Standards Institute (TIS. 20-2543) Standard for steel bars for reinforced concrete: Round bars

Thai Industrial Standards Institute (TIS. 24-2536) Standard for steel bars for reinforced concrete: Deformed bars

Testing sample

3 samples of 9 mm round bar reinforcing steel, RB9 (SR24) and 3 samples of 12 mm. deformed rebar, DB12 (SD30).

Figure 29 : Prepare the steel specimen

Figure 30 : After testing the steel specimen

3.3 Types of beam design

We classify 3 group of beams for comparing the different of surface effect by using steel bar on permanent formwork and look for comparison as reinforced concrete beam (Figure 31), Smooth interface U-shape permanent formwork beam (Figure 32) and Spike interface U-shape permanent formwork beam (Figure 33).

Figure 31 : RC beam Reference (RC).

Figure 32 : Smooth interface (ES).

Figure 33 : Spike interface (EK).

3.3.1 Reinforced concrete beam for reference (RC beam)

Create 3 reinforced concrete beam of 15x30x150 cm, which is mixed with the appropriate mix ratio obtained from experiments and using mixed design as 1:2:4 for mixed concrete and put 3DB12, 2DB12, RB9 @30, producing 3 blocks of 15 x 15 x15 centimeters, and curing for 28 days.

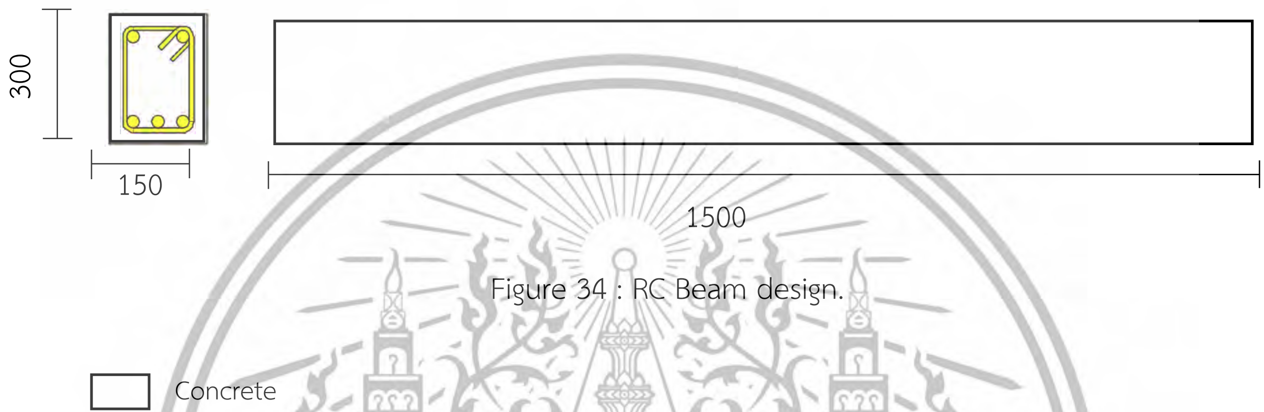

Figure 34 : RC Beam design.

Figure 35 : Picture of RC beam.

3.3.2 Beam by using U-shape permanent formwork with smooth surface (ES beam)

Create 3 **smooth** U-shape formwork of 15x30x150 cm with 25 mm thickness, which is mixed with the appropriate mix ratio obtained from experiments and using mixed design as 1:2:4 for mixed concrete and put 4DB12, RB9 @30, producing 3 blocks of 15 x 15 x15 centimeters, and curing for 28 days.

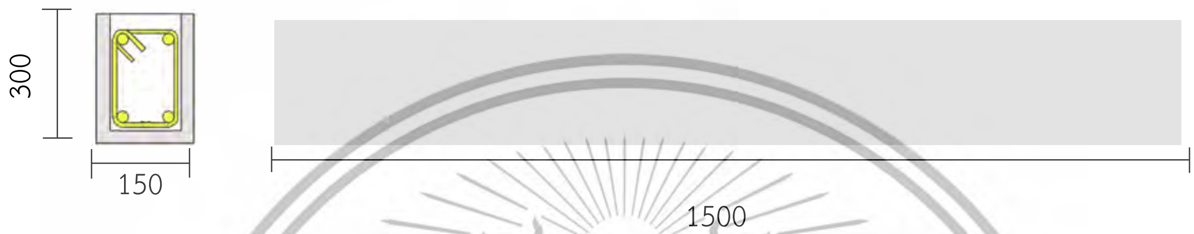

Figure 36 : ES beam design with smooth interface.

Mortar U-shape permanent formwork

Figure 37 : Picture of U-shape permanent formwork of ES.

3.3.3 Beam by using U-shape permanent formwork with spike surface

Create 3 **spike** U-shape formwork of 15x30x150 cm with 25 mm thickness, which is mixed with the appropriate mix ratio obtained from experiments and using mixed design as 1:2:4 for mixed concrete and put 4DB12, RB9 @30 and 4RB6 @20 cm on surface for being a spike and the length of each spike 2.5 cm and put in the middle of U-shape side, producing 3 blocks of 15 x 15 x15 centimeters, and curing for 28 days.

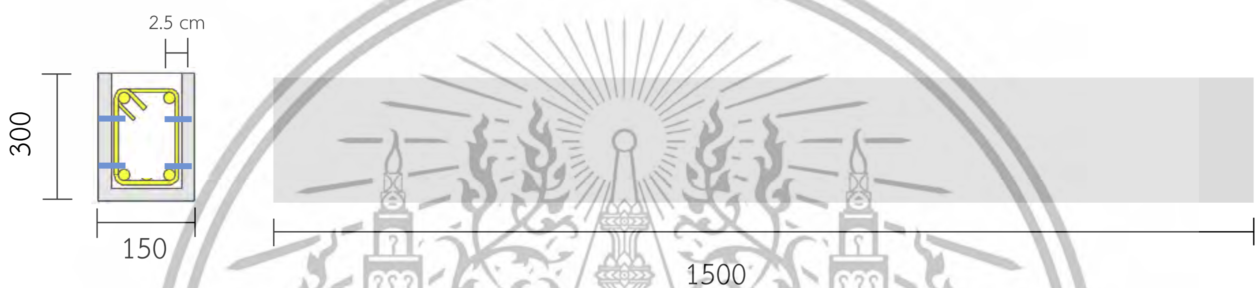

Figure 38 : EK beam design with spike interface.

Mortar U-shape permanent formwork 6-mm Round bar (Spike)

Figure 39 : Picture of U-shape permanent formwork of EK.

3.4 Beam casting procedure

RC beam, put steel bar and mixed concrete into permanent formwork

On figure 40 , using mixed design as 1:2:4 for mixed concrete and put, 4DB12, RB9 @30 from ACI standard calculation into U-shape formwork of 15x30x150 cm with 25 mm thickness and curing for 28 days (wrapping and spray water)

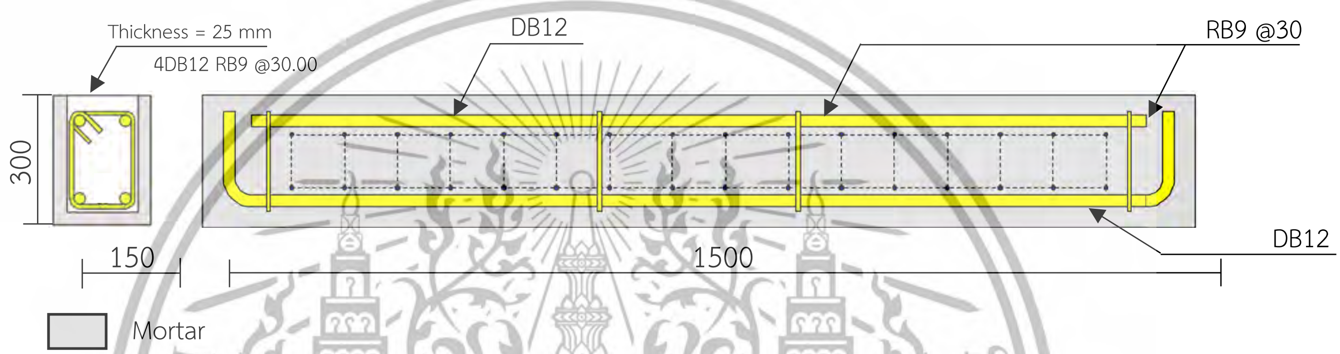

Figure 40 : Cross-section and reinforcement details.

3.4.1 Procedure for casting permanent formwork

a general procedure for casting a 15x30x150 cm permanent formwork beam with 2.5 cm of thickness

1. Prepare the formwork: Assemble the formwork according to the desired dimensions of the beam (15x30x150 cm in this case). The formwork can be made of wood, metal, or plastic, and should be strong enough to support the weight of the wet concrete.
2. Remove the formwork.
3. Finish the beam: If desired, you can smooth the surface of the beam using a trowel or grinder. You can also apply a protective coating to the beam to improve its durability.

3.4.2 Procedure for casting the beam by using permanent formwork

1. Prepare the U-shape permanent formwork with we prepared in 3.3.1.
2. Referring to Figure 41 , proceed to install the required reinforcement bars or mesh inside the U-shape formwork. It is essential to consult the structural drawings and specifications to ensure the correct placement and spacing of the reinforcement bars. This step is crucial as it provides the necessary strength and structural integrity to the beam. Pay close attention to accurately position the reinforcement within the formwork.

Figure 41: Install reinforced steel cage into permanent formwork.

3. Prepare the concrete mix according to the specifications provided. This involves accurately measuring and combining the appropriate proportions of cement, aggregates, and water. With the formwork in place, begin pouring the concrete mixture carefully into the U-shape formwork. Start from one end and progressively move towards the other end. During the pouring process, it is recommended to use a vibrator to remove any air pockets and ensure proper compaction of the concrete. This helps to minimize voids and enhance the structural strength of the

beam. It is essential to monitor the pour to ensure an even distribution of the concrete throughout the formwork.

4. Referring to Figure 42, after pouring the concrete, the surface requires finishing and the curing process needs to commence. Begin by screening the surface to achieve a smooth and level finish. Excess concrete can be removed using a trowel, ensuring a clean edge for the beam. To facilitate proper curing, the formwork should be covered with a curing compound or damp hessian. It is important to adhere to standard curing practices, which include keeping the concrete moist and protected from extreme temperature changes, for the specified duration as per the requirements of the concrete mix. Additionally, spraying water for curing should be implemented for 28 days to promote the development of concrete strength.

Figure 42 : Pour the concrete and have water curing after.

3.5 Test 4-point normal load setup

Test setup and loading protocol

The experimental setup for four-point tests is shown in Figure 43. All beams were loaded by a four-point bending load. The distance of 300 mm between two loading points was fixed to all beams. Two LVDTs were used to monitor the mid-span deflection and the other two were used to measure the displacement of bearings. For all beams, four strain gauges were attached at the surface of the specimen to record strain. The load was applied by a closed-loop hydraulic loading system. All beams were loaded from zero by an increment of 10 kilonewtons and then sustained for 10 s for the development of cracks up to a failure. It should be noted that the load bearings under the distribution beam were placed on the total width of composite beams.

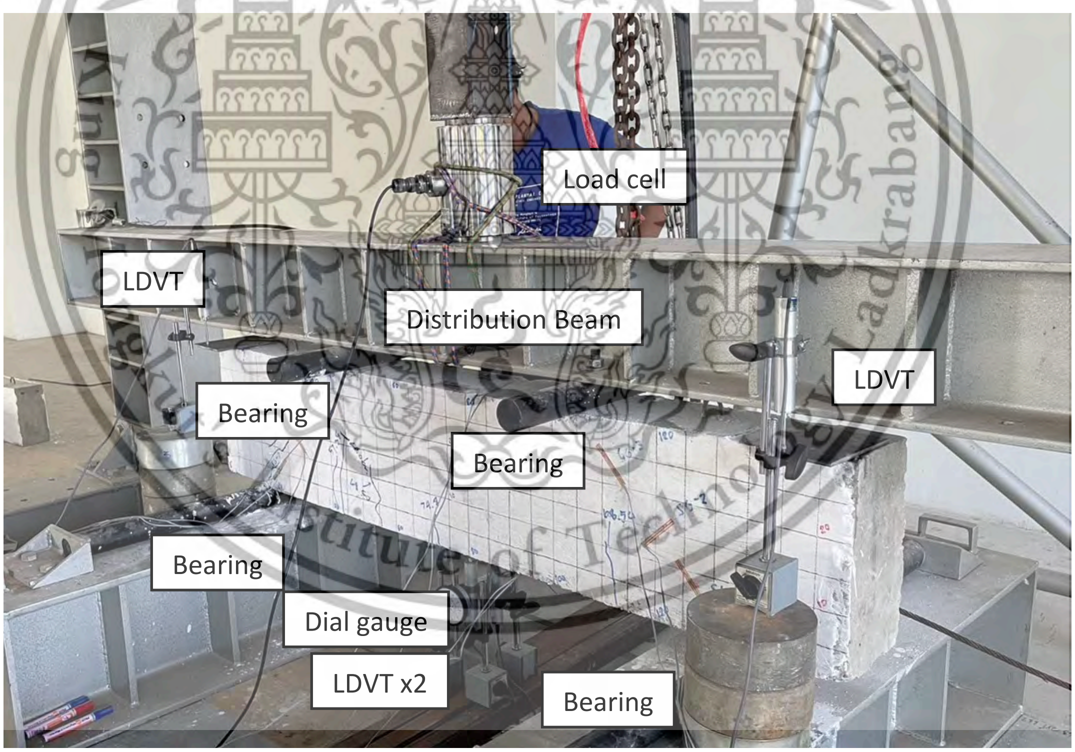

Figure 43 : Test setup and loading protocol

Beam preparation process

1. Draw the 5 cm gridline on horizontal and vertical line for observe the cracking information and behavior.

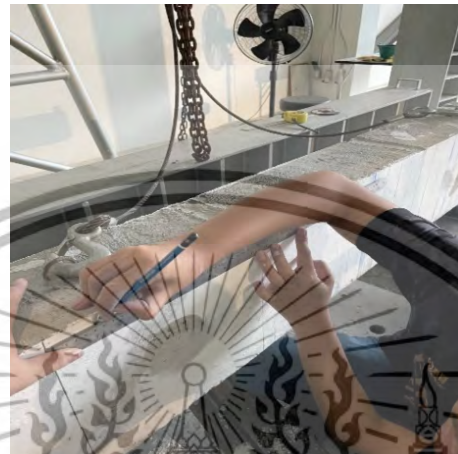

Figure 44 : Grid line drawing for clearly observation for cracking.

2. Use grinder to balance the surface of the beam by using spirit precision level like Fig. 45.

Figure 45: Surface finishing of all beam.

Procedure of beam testing

1. Prepare the beam into the testing machine, setting by make to position of two under bearing from 60 cm from middle of the beam for left- and right-hand side. On the two top/above bearing make 30 cm from middle of the beam for left- and right-hand side.

Figure 46 : Bearing setting with 30 cm from center of the beam.

2. Prepare the hydraulic load machine connect with load cell, and from hydraulic jack to hydraulic pump.

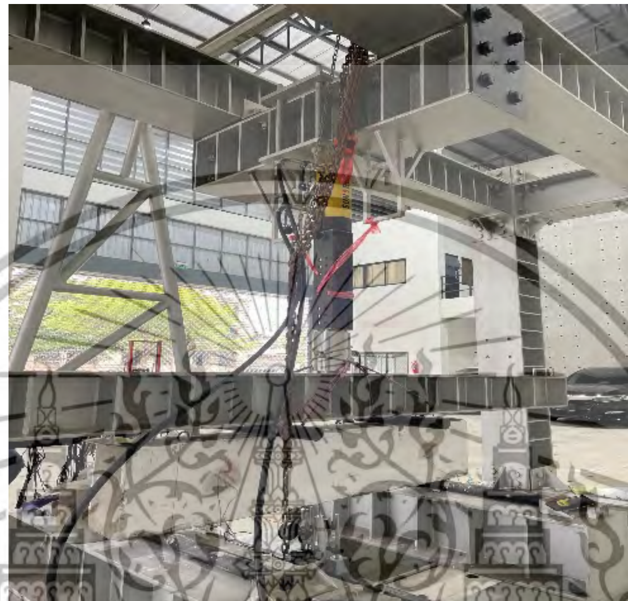

Figure 47: Hydraulic jack for giving load of the machine.

Figure 48: Hydraulic pump for control the load.

3. Connect the LVDT and strain gauge with data logger and load cell with load monitor and prepare the software of data logger and set the information of the channel by channel and checking the status for testing of the experiment.

Figure 49 : Data logger and Load cell preparation.

Figure 50 : Software of data logger.

4. Give the pre-load with 10-kN and go back to zero and have zero reset on monitor.

5. For start all beams were loaded from zero by an increment of 10 kilonewtons and then sustained for 10 s for the development of cracks up to a failure (maximum load for the beam), stop for each 10 kN and draw the cracking of the beam as shown in Fig. 51

Figure 51 : Record and draw the cracking of the beam.

CHAPTER 4

RESULT AND CALCULATION

4. Results of beam tests and discussions

4.1 Standard of Materials

Strength of materials used in research When tested according to the values are shown in Table 4

Material	Yield strength (MPa)	Ultimate strength (MPa)	Elastic Modulus (MPa)
Mortar	-	23.97	22.4 x 10^3
Concrete	-	32.26	24.6 x 10^3
12-mm Deformed bar	430.15	595.24	198.4 x 10^3
9-mm Round bar	316.28	440.63	187.9 x 10^3
6-mm Round bar	300.13	425.64	184.8 x 10^3

Table 4 : Strength of materials used in the beam

4.2. Load vs. mid-span deflection

Figure 52 illustrates the load versus mid-span deflection curves for all beams, including the RC, ES, and EK beams. The mid-span deflection values represent the average measurements obtained from two LVDTs positioned at the mid-span of each beam. It was observed that the peak loads in all composite beams significantly increased compared to the RC-ref beam, primarily due to the presence of the Mortar U-shape permanent formwork.

Among the composite beams, the ES beams exhibited the largest mid-span deflection at the peak loads, indicating the lowest stiffness among the composite beams within the shear carrying capacity of the RC-ref beam. This behavior can be attributed to the cracking of the core concrete in all composite beams, causing the load to transfer to the Mortar U-shape permanent formwork. The reduced integrity of the ES beams, resulting from transverse debonding between the Mortar U-shape permanent formwork and the core concrete, led to a smaller stiffness and more significant mid-span deflection.

In contrast, the EK beams demonstrated stronger interfacial bonding, resulting in improved integrity and higher stiffness. Consequently, the mid-span deflection of EK beams was smaller compared to that of ES beams.

Table 5 summarizes the key parameters derived from the experimental results, providing a concise overview of the findings.

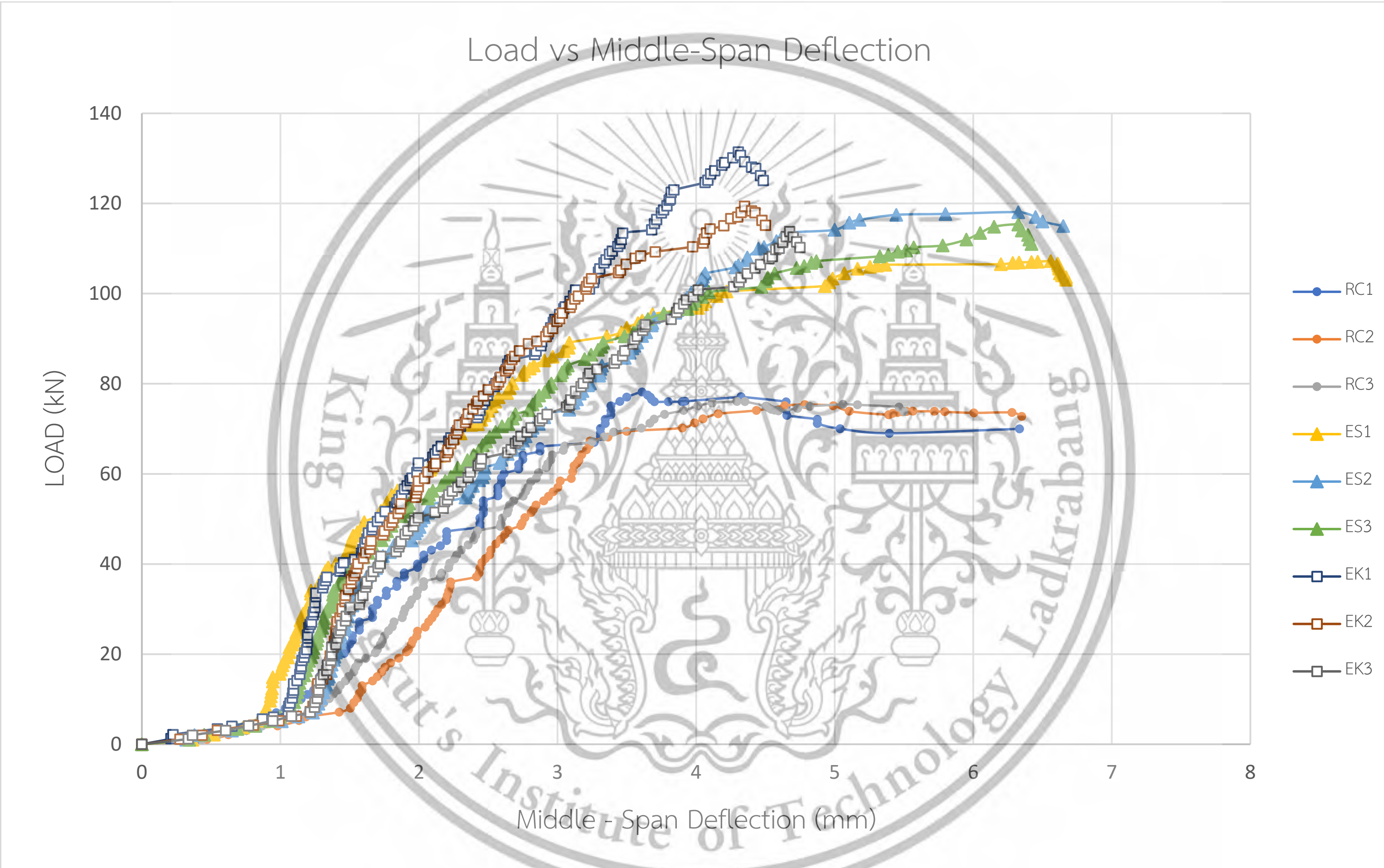

Figure 52: Load vs. mid-span deflection curves.

4.3. Shear carrying and deformation capacities

Table 5 provides a comparison of the shear carrying and deformation capacities of all beams relative to the reference reinforced concrete (RC-ref) beam. The shear carrying capacities, as determined from the shear force diagram in Figure 56 and the bending moment diagram in Figure 57, increased by a range of 40.7% to 71.71% across the composite beams. Similarly, the deformation capacities of the composite beams showed an increase ranging from 1.77% to 55.08% compared to the RC-ref beam. These improvements were observed regardless of the thickness of the permanent formwork and the interfacial properties.

Among all the composite beams, those with a permanent formwork thickness of 20 mm exhibited the highest shear carrying capacity within their respective series. However, the variation in shear carrying capacities was less pronounced in the EK beams compared to the other series.

Furthermore, in Figure 55, when a point load equivalent to 100 kN was applied as a reference, it can be observed that the deformation of the EK beam was lower than that of the ES beam. This suggests that the shear key, represented by the spikes, assists in resisting deflection, aligning with the intended purpose of its inclusion in the design.

Group	Beam	Shear capacity (kN)	Mid-span Deflection (mm)
1	RC1	39.085	3.61
	RC2	37.68	4.785
	RC3	38.04	4.295
2	ES1	53.605	6.56
	ES2	59.035	6.325
	ES3	57.665	6.325
3	EK1	65.715	4.305
	EK2	59.69	4.35
	EK3	56.885	4.675

Table 5 : Shear carrying capacities vs. mid-span deflection at peak load.

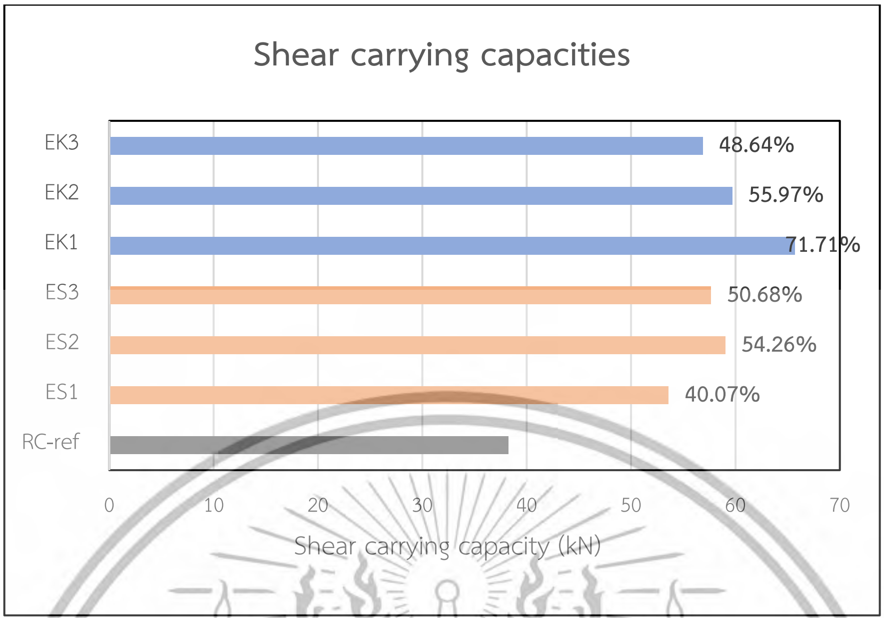

Figure 53: Shear carrying capacities comparison with RC-ref.

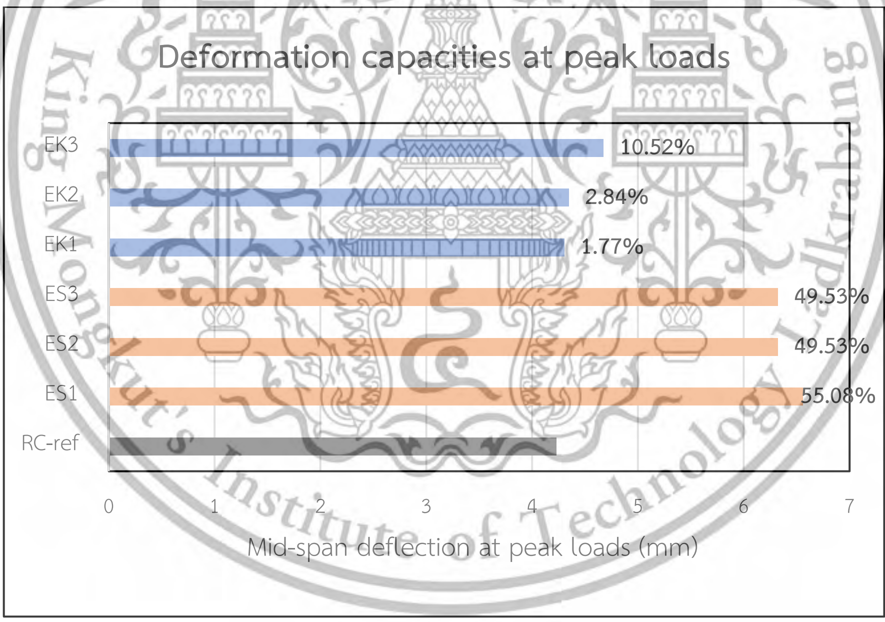

Figure 54: Mid-span deflection comparison with RC-ref.

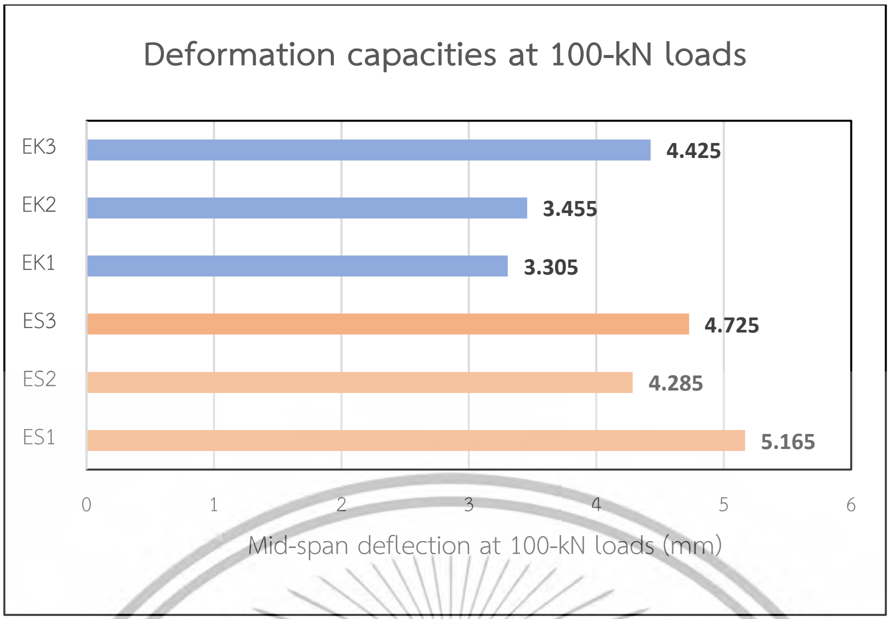

Figure 55 : Deformation comparison at 100-kN load.

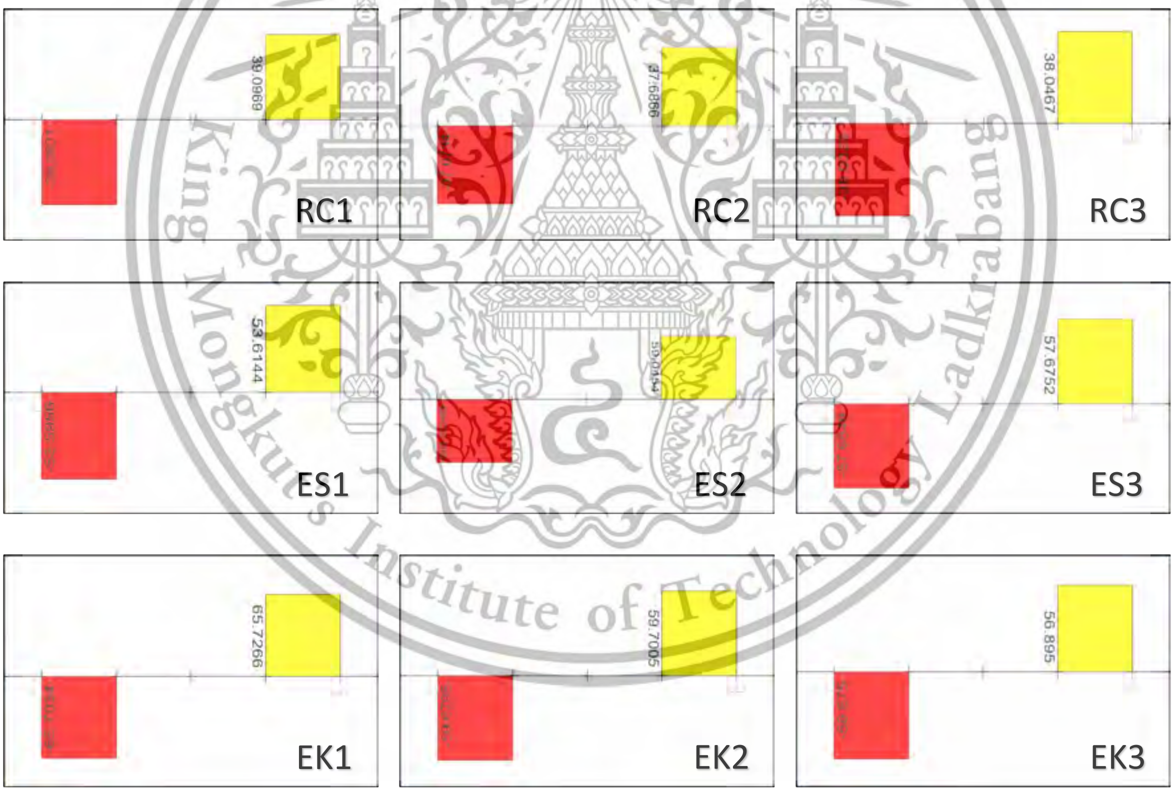

Figure 56: Shear force diagram of all beams.

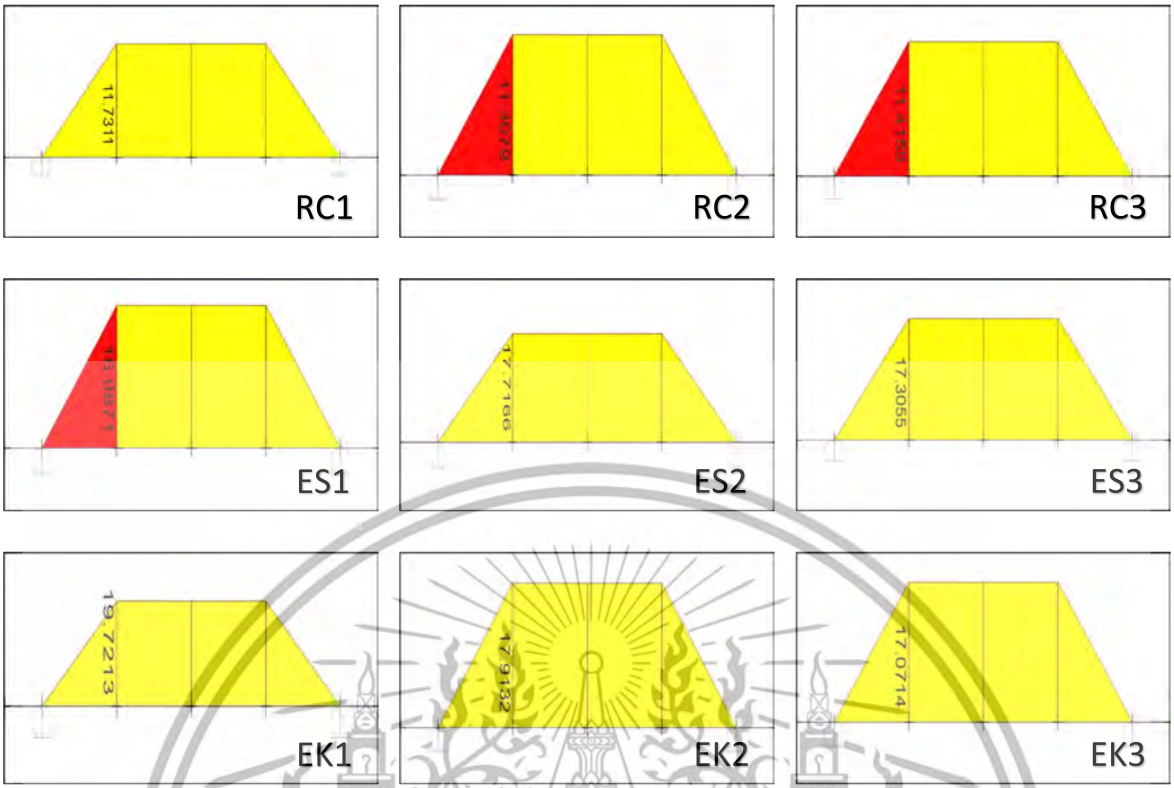

Figure 57: Bending moment diagram of all beams.

4.4. Cracking behavior and failure modes

4.4.1 Cracking behavior

Figure 58 presents a visual representation of the visible cracks observed in all beams at the peak load, including the critical cracks. It is important to note that composite beams using Mortar U-shape permanent formwork displayed a few fine cracks. However, due to the limited crack observation time during the loading tests, a comprehensive assessment of crack development was challenging.

Initially, flexural cracks were observed within the pure bending zone of all beams. As the loading progressed, an increasing number of flexural cracks appeared within the shear spans of all beams. In the case of the RC-ref beam, once an inclined crack developed within the shear span, the load-carrying capacity decreased significantly, accompanied by a fracture sound.

Comparatively, the ES beams exhibited fewer inclined cracks when compared to the EK beams.

Figure 58 : Crack patterns at the peak loads.

4.4.2 Bonding checking

In all the composite beams tested, it was observed that multiple inclined cracks appeared, whereas in the case of the reference reinforced concrete (RC-ref) beam, only one crack was observed. Additionally, after the loading test, the cracks at the interface between the permanent formwork and concrete in all composite beams were examined.

Fig.59 illustrates the bonding mechanism of ES beams and EK beams, showcasing the presence of shear keys, represented by spikes. These shear keys play a crucial role in connecting the inner concrete and the U-shape formwork together, distinguishing the EK beams from the ES beams, which clearly exhibited debonding behavior.

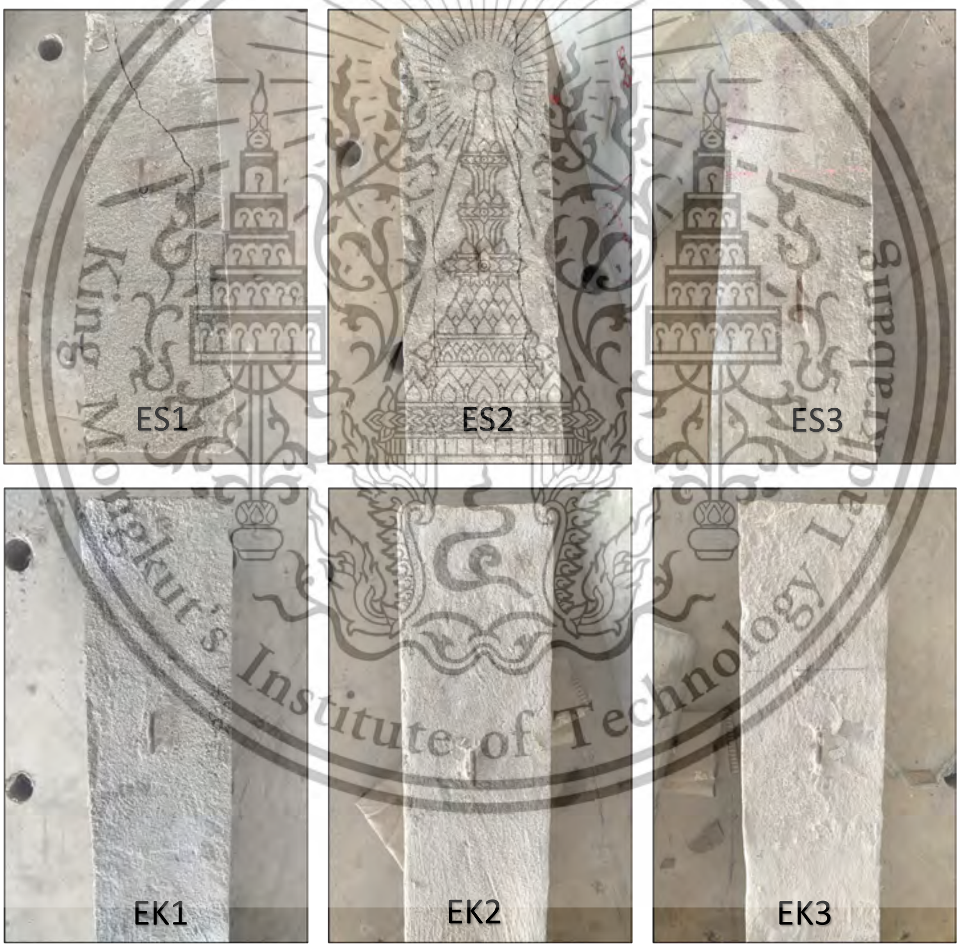

Figure 59 : Debonding patterns at the peak loads.

4.4.3 Failure mode of the cracking beam

Based on the experimental results, it was observed that both RC beams (Group 1) and ES beams (Group 2) exhibited similar cracking behavior, characterized by diagonal shear failure. However, in the case of EK beams (Group 3), EK1 and EK3 beams also showed diagonal shear failure, while EK2 beam displayed flexural failure as figure 4.9.

Regarding debonding, the ES beams displayed noticeable debonding cracks when viewed from the top, indicating a separation between the beam and its surrounding material. On the other hand, the EK beams did not exhibit any debonding due to the presence of shear keys, which prevented such separation between the beam and its surroundings.

Figure 60 : Flexural failure and diagonal shear failure picture.

CHAPTER 5

CONCLUSION AND DISCUSSION

This research investigates the failure behavior of formwork to shear strength of precast reinforced concrete beams under 4-point loading with variation between different surfaces.

5.1 Beam behavior

5.1.1 Load capacities behavior

The relationship between the load and the center deflection of the formwork girder length is observed to be a straight line initially. This indicates that the beam exhibits linear elastic behavior. However, as the force acting on the beam approaches around 80-85 percent of the maximum load, the tensile steel reinforcement begins to yield. This can be identified by the occurrence of cracks at the center of the beam length. Subsequently, during the second or highest load level, shear cracks in the form of shear crack will become visible.

The smooth surface beam (Group 2) and spike surface beam (Group 3) exhibit higher linear elastic strength compared to the reference beam (Group 1), with an increase ranging from 40.7% to 71.71%. This higher strength can be attributed to the presence of U-embedded steel reinforcement in these beams, which contributes to the overall strength enhancement. Additionally, the steel case inside the beam further contributes to its strength.

5.1.2 Deformation behavior and shear key

The deformation observed in all beams differs at peak loads. However, the researcher aims to compare the efficiency of the surface between the ES beam and the EK beam. By examining the deflection at a load of 100 kN and at peak loads, it is evident that the spike surface of the EK beam exhibits less deflection compared to the smooth surface of the ES beam. This indicates that incorporating a shear key in the form of a spike, using RB6, enhances the efficiency of the EK beam in resisting beam deflection.

5.1.3 Cracking behavior and failure modes

From the result of experiment, RC beam (Group 1) and ES beam (Group 2) have the cracking behavior as the same, that's diagonal shear failure but in EK beam (Group 3), EK1 and EK3 beam is diagonal shear failure but EK2 beam is flexural failure.

And debonding, the ES beam have clearly debonding crack from top view of the beam but EK beam have no debonding because of the shear key

5.2 Suggestion for using the product

The researchers suggest the user, customer, or developer to use the spike surface mortar U-shape permanent formwork. The efficiency of load capacities and resisting of deflection have more than the smooth surface beam comparison and If we compare with RC-ref, it helps to decrease the time to install the formwork for producing the beam in construction work area.

5.3 Research limitations

5.3.1 The length of the beam is 1.50 meters which may be too little as a result, the test results are not as comprehensive as they should be.

5.3.2 By using only 4 points of loads , which is different from the actual usage condition, which is a load that transfers force from the slab in a uniformly distributed load.

5.3.3 The machine for giving the load is a manual control so the load will be unsteady like digital control.

5.4 Suggestions for further research

5.4.1 Should install strain gauge in inside the beam at middle span of steel case/reinforced case for study the relation of stress and strain of the beam.

5.4.2 Should have more different thickness of specimen of U-shape permanent formwork as 15, 20 ,25 mm of thickness.

5.4.3 Using other material for mixed design of permanent formwork development such as cellular lightweight concrete, using polymer fiber for mixed design etc. for develop any part of the result

Reference

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Appendix I

Data of loads and mid-span deflection of reinforced concrete beam

(RC beam)

RC1		RC2		RC3	
Load	Mid-Def	Load	Mid-Def	Load	Mid-Def
0	0	0	0	0	0
1	0.4	1.03	0.47	1.015	0.435
2.13	0.475	2.09	0.625	2.11	0.55
3.05	0.755	3	0.665	3.025	0.71
3.97	0.755	4.08	0.98	4.025	0.8675
5	0.855	5.25	1.135	5.125	0.995
6.07	0.915	6.05	1.185	6.06	1.05
7	0.97	7.12	1.425	7.06	1.1975
7.96	1.035	8	1.505	7.98	1.27
9.07	1.095	9.25	1.53	9.16	1.3125
10.06	1.15	10.2	1.555	10.13	1.3525
11.05	1.195	11.32	1.57	11.185	1.3825
11.99	1.24	12.05	1.59	12.02	1.415
13.12	1.275	13	1.59	13.06	1.4325
14.07	1.275	14.05	1.665	14.06	1.47
15.07	1.285	15	1.7	15.035	1.4925
16.13	1.33	16.02	1.73	16.075	1.53
17.14	1.33	17.08	1.755	17.11	1.5425
18.13	1.33	18.03	1.795	18.08	1.5625
19.02	1.38	19.1	1.855	19.06	1.6175
20.12	1.46	20.5	1.91	20.31	1.685
20.94	1.475	21	1.925	20.97	1.7
22.2	1.5	22.15	1.945	22.175	1.7225
23.05	1.52	23	1.955	23.025	1.7375
24.1	1.52	24	1.985	24.05	1.7525
25.32	1.57	25.09	1.99	25.205	1.78
26.12	1.57	26	2.045	26.06	1.8075
27.17	1.57	27.15	2.07	27.16	1.82
28.13	1.665	28.04	2.095	28.085	1.88

29.25	1.665	29	2.115	29.125	1.89
30.07	1.665	30	2.135	30.035	1.9
30.98	1.7	31	2.165	30.99	1.9325
31.96	1.7	32.08	2.195	32.02	1.9475
32.98	1.765	33	2.205	32.99	1.985
34.02	1.765	34	2.215	34.01	1.99
35	1.84	35	2.225	35	2.0325
36.13	1.84	36	2.23	36.065	2.035
37.07	1.895	37.13	2.415	37.1	2.155
38.03	1.895	38	2.435	38.015	2.165
39.24	1.99	39.09	2.44	39.165	2.215
40.01	1.99	40.32	2.455	40.165	2.2225
41.1	2.035	41.18	2.48	41.14	2.2575
42.01	2.035	42	2.51	42.005	2.2725
43.11	2.09	43.08	2.52	43.095	2.305
44.02	2.155	44.44	2.555	44.23	2.355
45.2	2.2	45.48	2.59	45.34	2.395
46.19	2.2	46.53	2.62	46.36	2.41
47.2	2.2	47.5	2.645	47.35	2.4225
48.2	2.44	48.51	2.735	48.355	2.5875
49	2.44	49.08	2.745	49.04	2.5925
50.17	2.44	50.27	2.765	50.22	2.6025
51.24	2.465	51.4	2.81	51.32	2.6375
52.01	2.465	52.07	2.825	52.04	2.645
53.11	2.465	53.09	2.845	53.1	2.655
54.01	2.465	54	2.900727	54.005	2.682864
55.11	2.57	55	2.934864	55.055	2.752432
56.16	2.57	56	2.969	56.08	2.7695
57.04	2.57	57	3.003136	57.02	2.786568
58.02	2.595	58.43	3.02	58.225	2.8075
59.06	2.595	58.98	3.1	59.02	2.8475
60.08	2.615	60.46	3.11	60.27	2.8625

61.08	2.72	61.77	3.12	61.425	2.92
62.1	2.72	62.35	3.14	62.225	2.93
63.19	2.75	63.01	3.155	63.1	2.9525
64.12	2.75	64.26	3.175	64.19	2.9625
65.07	2.875	65.35	3.21	65.21	3.0425
66.04	2.875	66.36	3.23	66.2	3.0525
67	3.265	67.29	3.235	67.145	3.25
68.27	3.31	68.14	3.365	68.205	3.3375
69.11	3.31	69.43	3.5	69.27	3.405
70.08	3.31	70.18	3.9	70.13	3.605
71.17	3.345	71.3	3.99	71.235	3.6675
72.1	3.345	72.21	4.05	72.155	3.6975
73.11	3.385	73.32	4.16	73.215	3.7725
74.07	3.385	74.08	4.435	74.075	3.91
75.07	3.385	75.14	4.64	75.105	4.0125
76.08	3.45	75.36	4.785	75.72	4.1175
77.04	3.5	75.12	4.99	76.08	4.295
78.17	3.61	73.9	5.105	76.035	4.3525
77.5	3.65	73.1	5.39	75.03	4.505
77	3.67	73.43	5.42	74.715	4.52
76.5	3.68	73.61	5.455	74.335	4.5425
76	3.7	73.77	5.49	74.135	4.5675
76	3.8	73.85	5.52	73.97	4.595
76	3.9	73.9	5.565	74.515	4.7325
76.11	3.92	73.87	5.72	74.99	4.82
77.07	4.325	73.77	5.795	75.42	5.06
77.1	4.325	73.54	6.005	75.32	5.165
75.98	4.65	73.62	6.28	74.8	5.465
74.94	4.65	72.75	6.35	73.845	5.5
74.16	4.65				
72.98	4.655				
72.09	4.875				

71.19	4.875				
70.02	5.04				
69	5.395				
70	6.335				

Appendix II

Data of loads and mid-span deflection of Smooth interface U-shape permanent formwork beam (ES beam)

ES1		ES2		ES3	
Load	Mid-Def	Load	Mid-Def	Load	Mid-Def
0	0	0	0	0	0
1.02	0.365	1	0.32	1.01	0.3425
2.15	0.52	2.05	0.38	2.1	0.45
3.72	0.73	3.04	0.65	3.38	0.69
4.08	0.81	4.11	0.82	4.095	0.815
5.2	0.84	5.11	1.01	5.155	0.925
6.03	0.865	6.16	1.13	6.095	0.9975
7.41	0.9	7.04	1.235	7.225	1.0675
8.02	0.9	8.17	1.255	8.095	1.0775
9.67	0.925	9	1.275	9.335	1.1
10.62	0.93	10.29	1.295	10.455	1.1125
11.56	0.935	11.55	1.31	11.555	1.1225
12.38	0.94	12.58	1.32	12.48	1.13
13.91	0.945	13.27	1.33	13.59	1.1375
14.86	0.945	14.54	1.34	14.7	1.1425
15.62	0.995	15	1.35	15.31	1.1725
16.55	1.005	16.28	1.365	16.415	1.185
17.53	1.015	17.68	1.37	17.605	1.1925
18.35	1.025	18.73	1.385	18.54	1.205
19.26	1.055	19.43	1.39	19.345	1.2225
20.45	1.065	20.37	1.4	20.41	1.2325
21.52	1.065	21.11	1.415	21.315	1.24
22.12	1.09	22.55	1.425	22.335	1.2575
22.98	1.1	23.12	1.43	23.05	1.265
23.83	1.105	24.26	1.435	24.045	1.27
24.81	1.115	25.51	1.455	25.16	1.285
25.64	1.135	26.06	1.47	25.85	1.3025
26.58	1.145	27.35	1.475	26.965	1.31
27.49	1.145	28.38	1.49	27.935	1.3175
29	1.165	29.87	1.495	29.435	1.33

30.15	1.195	30.81	1.52	30.48	1.3575
31	1.205	31.27	1.525	31.135	1.365
32	1.22	32.32	1.535	32.16	1.3775
33.41	1.22	33.02	1.54	33.215	1.38
34.1	1.22	34	1.55	34.05	1.385
35.58	1.285	35.02	1.56	35.3	1.4225
36.55	1.295	36.2	1.57	36.375	1.4325
37.72	1.325	37.28	1.625	37.5	1.475
38.45	1.325	38.58	1.67	38.515	1.4975
39.25	1.345	39.1	1.69	39.175	1.5175
40.08	1.4	40.48	1.7	40.28	1.55
41.37	1.46	41.76	1.74	41.565	1.6
42.31	1.48	42.65	1.79	42.48	1.635
43.4	1.5	43.82	1.815	43.61	1.6575
44.31	1.505	44.2	1.82	44.255	1.6625
45.31	1.515	45.23	1.95	45.27	1.7325
46.27	1.525	46.84	1.97	46.555	1.7475
47.07	1.555	47.48	1.985	47.275	1.77
48.7	1.6	48.22	2.005	48.46	1.8025
49.3	1.605	49.64	2.015	49.47	1.81
50.86	1.71	50.37	2.035	50.615	1.8725
51.78	1.725	51.4	2.065	51.59	1.895
52.74	1.76	52.52	2.075	52.63	1.9175
53.63	1.77	53.22	2.085	53.425	1.9275
54.34	1.795	54.75	2.335	54.545	2.065
55.32	1.805	55.39	2.34	55.355	2.0725
56.32	1.845	56.14	2.355	56.23	2.1
57.65	1.94	57.33	2.39	57.49	2.165
58.35	1.945	58.57	2.435	58.46	2.19
59.48	2	59.22	2.46	59.35	2.23
60.93	2.08	60.16	2.47	60.545	2.275
61.42	2.085	61.36	2.475	61.39	2.28

62	2.1	62.37	2.58	62.185	2.34
63	2.105	63.12	2.595	63.06	2.35
64	2.15	64.42	2.64	64.21	2.395
65	2.185	65.36	2.68	65.18	2.4325
66	2.2	66.74	2.72	66.37	2.46
67	2.22	67.38	2.75	67.19	2.485
68	2.25	68.34	2.77	68.17	2.51
69	2.3	69.6	2.805	69.3	2.5525
70.89	2.3775	70.22	2.82	70.555	2.59875
71	2.425	71.12	2.865	71.06	2.645
72	2.45	72.55	2.905	72.275	2.6775
73	2.475	73.47	2.915	73.235	2.695
74	2.5	74.25	3.085	74.125	2.7925
75	2.525	75.77	3.115	75.385	2.82
76	2.55	76.55	3.14	76.275	2.845
77	2.575	77.8	3.16	77.4	2.8675
77.97	2.635	78.39	3.18	78.18	2.9075
79	2.655	79.63	3.22	79.315	2.9375
80.06	2.675	80.06	3.235	80.06	2.955
81.96	2.745	81.8	3.3	81.88	3.0225
82.72	2.76	82.39	3.305	82.555	3.0325
83.37	2.8	83.3	3.31	83.335	3.055
84.07	2.83	84.04	3.32	84.055	3.075
85.17	2.905	85.76	3.485	85.465	3.195
86	2.965	86.89	3.52	86.445	3.2425
87.25	3.045	87.85	3.54	87.55	3.2925
88	3.08	88.44	3.555	88.22	3.3175
89.1	3.085	89.14	3.575	89.12	3.33
90.49	3.355	90.58	3.61	90.535	3.4825
91.38	3.46	91.43	3.64	91.405	3.55
92.42	3.5	92.95	3.68	92.685	3.59
93.5	3.58	93.5	3.685	93.5	3.6325

94	3.61	94.7	3.695	94.35	3.6525
95.43	3.685	95.76	3.85	95.595	3.7675
96.85	4.015	96.31	3.865	96.58	3.94
97.66	4.045	97.74	3.9	97.7	3.9725
98.3	4.065	98.48	3.915	98.39	3.99
99.44	4.15	99.08	3.935	99.26	4.0425
100.47	4.22	100.23	3.965	100.35	4.0925
101.68	4.93	101.37	4.015	101.525	4.4725
102.52	4.96	102.92	4.045	102.72	4.5025
103.35	4.985	103.77	4.05	103.56	4.5175
104.5	5.07	104.47	4.065	104.485	4.5675
105.55	5.165	105.82	4.285	105.685	4.725
105.96	5.255	106.29	4.305	106.125	4.78
106.22	5.305	107.43	4.36	106.825	4.8325
106.41	5.365	108.03	4.37	107.22	4.8675
106.53	6.2	109.99	4.45	108.26	5.325
106.82	6.285	110.34	4.49	108.58	5.3875
106.92	6.33	111.67	4.58	109.295	5.455
107.01	6.42	112.09	4.61	109.55	5.515
107.07	6.465	113.5	4.675	110.285	5.57
107.21	6.56	114.15	5	110.68	5.78
106.68	6.61	115.76	5.105	112	5.95
106.27	6.615	116.38	5.18	113.46	6.05
105.9	6.62	117.48	5.445	114.85	6.15
105.52	6.62	117.68	5.8	115.33	6.325
104.51	6.625	118.07	6.325	114	6.35
104.05	6.64	117	6.45	113	6.395
103.65	6.67	116	6.5	112	6.405
103.1	6.67	115	6.65	111	6.42

Appendix II

Data of loads and mid-span deflection of Spike interface U-shape permanent formwork beam (EK beam)

EK1		EK2		EK3	
Load	Mid-Def	Load	Mid-Def	Load	Mid-Def
0	0	0	0	0	0
1.26	0.21	1.13	0.275	1.2	0.335
2.12	0.225	2	0.435	2	0.365
3.43	0.545	3.1	0.545	3.07	0.605
4.01	0.65	4.23	0.805	4.1	0.77
5.61	0.87	5.22	0.99	5.2	0.945
6.03	0.95	6.22	1.115	6.23	1.08
7.3	1.055	7.24	1.215	7.12	1.215
8.42	1.06	8.42	1.235	8.23	1.245
9.16	1.07	9.25	1.25	9.33	1.25
10.29	1.085	10.1	1.265	10.2	1.265
11.4	1.09	11.25	1.265	11.58	1.275
12	1.095	12.97	1.265	12.03	1.275
13.42	1.095	13.43	1.27	13.58	1.29
14.16	1.12	14.46	1.305	14.24	1.29
15.52	1.14	15.51	1.335	15.46	1.31
16.79	1.145	16.85	1.34	16.38	1.335
17.28	1.15	17.48	1.345	17.57	1.34
18.6	1.155	18.23	1.355	18.62	1.365
19.31	1.17	19.58	1.36	19.61	1.37
20.25	1.175	20.07	1.37	20	1.37
21.02	1.19	21.54	1.38	21.55	1.37
22.67	1.195	22.88	1.39	22.12	1.4
23.54	1.195	23.61	1.4	23.58	1.41
24.26	1.195	24.95	1.4	24.7	1.42
25.9	1.205	25.07	1.405	25.28	1.435
26.62	1.215	26.66	1.405	26.42	1.44
27.12	1.225	27.21	1.41	27.39	1.47
28.72	1.235	28.03	1.43	28.42	1.475
29.35	1.24	29.44	1.445	29.95	1.5
30.35	1.25	30.02	1.445	30.38	1.505
31.45	1.25	31.67	1.465	31.01	1.57
32.75	1.255	32.34	1.465	32.47	1.575
33.52	1.255	33.05	1.47	33.05	1.595
34.71	1.305	34.4	1.49	34.87	1.615
35.51	1.31	35.7	1.51	35.67	1.625
36.31	1.325	36.56	1.51	36.06	1.625
37.09	1.335	37.39	1.53	37.3	1.655
38.43	1.43	38.05	1.54	38.34	1.67
39.11	1.435	39.04	1.55	39.22	1.705
40.29	1.455	40.03	1.56	40.06	1.72
41.04	1.535	41.29	1.6	41.72	1.725

42.38	1.585	42.51	1.615	42.73	1.835
43.2	1.595	43.3	1.645	43.82	1.855
44.73	1.61	44.36	1.65	44.48	1.86
45.53	1.625	45.08	1.655	45	1.87
46.89	1.635	46.49	1.74	46.6	1.9
47.58	1.66	47.31	1.75	47.37	1.92
48.25	1.665	48.62	1.785	48.35	1.96
49.44	1.7	49.24	1.805	49.61	1.97
50.3	1.72	50.19	1.815	50.24	1.995
51.66	1.755	51.2	1.85	51.46	2.115
52.72	1.825	52.28	1.865	52.41	2.175
53.6	1.84	53.36	1.87	53.85	2.185
54.33	1.855	54.82	1.975	54.28	2.205
55.17	1.875	55.66	1.98	55.38	2.215
56.62	1.895	56.47	1.985	56.17	2.24
57.36	1.915	57.13	1.995	57.04	2.28
58.52	1.935	58.4	1.995	58.21	2.305
59.06	1.95	59.01	2.04	59.18	2.355
60.31	1.985	60.43	2.065	60.39	2.37
61.82	1.995	61.66	2.105	61.85	2.425
62.41	1.995	62.3	2.12	62.24	2.445
63.69	2.1	63.84	2.19	63.33	2.45
64.43	2.115	64.73	2.205	64.75	2.64
65.29	2.135	65.28	2.21	65.38	2.665
66.12	2.16	66.78	2.23	66.8	2.695
67.29	2.215	67.56	2.25	67.28	2.715
68	2.23	68.93	2.27	68.35	2.735
69.2	2.27	69.66	2.28	69.28	2.78
70.58	2.3	70.84	2.29	70.24	2.81
71.48	2.335	71.4	2.335	71.74	2.87
72.49	2.42	72.07	2.345	72.35	2.89
73.22	2.43	73.29	2.355	73.19	2.925
74.06	2.44	74.37	2.39	74.86	3.065
75.45	2.46	75.53	2.415	75.24	3.085
76.28	2.475	76.15	2.425	76.44	3.095
77.47	2.495	77.28	2.465	77.9	3.13
78.26	2.5	78.68	2.5	78.33	3.13
79.4	2.545	79.83	2.56	79.37	3.17
80.08	2.555	80.37	2.575	80.09	3.185
81.3	2.585	81.44	2.59	81.4	3.22
82.5	2.62	82.85	2.625	82.3	3.23
83.14	2.63	83.35	2.645	83.21	3.285
84.35	2.64	84.08	2.655	84.56	3.41
85.16	2.655	85.39	2.67	85.33	3.425
86.5	2.835	86.08	2.69	86.19	3.47

87.23	2.845	87.31	2.725	87.3	3.485
88.45	2.88	88.9	2.79	88.78	3.545
89.35	2.885	89.42	2.85	89.81	3.555
90.49	2.92	90.45	2.915	90.52	3.575
91.07	2.93	91.58	2.935	91.86	3.615
92.43	2.95	92.27	2.965	92.67	3.63
93.62	2.97	93.84	2.995	93.15	3.635
94.25	2.98	94.47	3.015	94.29	3.82
95.38	3.015	95.68	3.035	95.85	3.86
96.65	3.045	96.95	3.09	96.74	3.875
97.08	3.055	97.62	3.1	97.7	3.91
98.28	3.09	98.81	3.125	98.6	3.93
99.5	3.115	99.44	3.15	99.3	3.98
100.79	3.13	100.99	3.205	100.81	4.015
101.02	3.23	101.58	3.21	101.53	4.27
102.49	3.26	102.53	3.225	102.53	4.31
103.32	3.265	103.32	3.245	103.57	4.325
104.77	3.295	104.68	3.44	104.43	4.37
105.51	3.305	105.19	3.455	105.66	4.425
106.82	3.335	106.53	3.495	106.47	4.465
107.51	3.35	107.87	3.56	107.75	4.525
108.76	3.375	108.38	3.6	108.24	4.55
109.44	3.395	109.27	3.705	109.79	4.575
110.45	3.435	110.41	3.975	110.03	4.6
111.12	3.45	111.25	4.05	111.36	4.625
112	3.46	112.08	4.06	112.66	4.65
113.44	3.47	113.48	4.075	113.77	4.675
114.18	3.68	114.35	4.1	112.56	4.7
115.56	3.7	115.08	4.2	111.48	4.725
116.45	3.715	116.64	4.25	110.25	4.75
117.89	3.75	117	4.3		
118.58	3.765	118	4.325		
119.48	3.79	119.38	4.35		
120.73	3.805	118.35	4.4		
121	3.815	117.98	4.425		
122.49	3.82	116.25	4.475		
123.01	3.84	115.16	4.5		
124.66	4.065				
125.19	4.085				
126.57	4.105				
127.28	4.135				
128.48	4.185				
129.09	4.205				
130.13	4.265				
131.43	4.305				

130.7	4.32				
129.27	4.35				
128.09	4.4				
127.79	4.43				
126.18	4.465				
125.13	4.485				

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