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Structural behaviour of Insulated Concrete Form (ICF) Walls in Comparison to Traditional Types of Bearing Walls

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ملخص عربي:
يتناول هذا البحث دراسة معملية مبنية على المقارنة بين هذه التكنولوجيا الحديثة والأنظمة التقليدية باعتبارها أكثر ملائمة للدول النامية نظرًا لقلة تكلفتها وتوفيرها للطاقة والعزل وسهولة تطبيقها واعاده تجسيد العناصر الانشائية بروح عصرية. ويهدف البحث الي دراسه تأثير البلوك الفليني علي العنصر الخرساني تحت تأثير الأحمال الرأسية, بالإضافة إلى عمل مقارنة بين هذا النظام الحديث والانظمة الأخرى من الحوائط الحاملة من حيث الحمل والإنبعاج حيث تم في هذا البحث دراسه سلوك مجموعه من 8 حوائط بطول 120 سم وارتفاع 80 سم علي مجموعتين تخانه 10 سم و20 سم من (طوب - بلوكات اسمنتية - خرسانة مسلحة) بالمقارنة بنظام انشائي من (خرسانه معزوله بشده فلينيه) ودراسة الشروخ، وأثناء الاختبار المعملي تم توثيق عدة نتائج مثل: شكل تشرخ العينات، وطبيعة الانهيار، ، وحمل الانهيار، وعلاقة الحمل والانفعال؛ ومن ثم تم تحليل هذه القياسات، ومقارنة الحوائط المختلفة طبقًا لمتغيراتها.

Abstract

The insulated concrete form (ICF) system is now accepted in generality establishments in the developed countries and it has become part of many building codes. It is used because of its advantages as light weight and energy efficiency. This study presents an extensive study on the behavior of conventional bearing walls such as, bricks, blocks, and concrete in comparison to insulated concrete form (ICF) Walls. Eight walls (1200 X 800 mm) of bricks, concrete, blocks and ICF with different width (120 and 250 mm) were built up and tested experimentally. The main objective of this study is to compare the effect of using foam in ICF wall and the traditional system of bearing walls. The experimental results proved that ICF is a good alternative compared with the traditional system of bearing walls. Using ICF as intelligent buildings compared to traditional building materials will lead to a perfect system that can improve building comfort and economic efficiency.

Key Words: ICF, Foam, Bearing Walls

1. Introduction

The bearing walls are conspicuously considered one of the oldest structural systems used in construction, although these systems have a lot of defects that had been proven, they didn't turn obsolete. Recently, bearing walls have been re-introduced and a lot of efforts have been made to get rid of those defects. In this study, the technology used emerged in 1960 to rectify the idea of the traditional bearing walls to add new features to it such as; (durability, Strength - heat Isolation, cost reduction, time saving, quite environment, fire resistance, energy efficiency, and environmentally friendly). This technology is called Insulated Concrete Form (ICF). Many studies that talk about the behavior of this system found along with the importance of its use as an alternative to skeleton structure systems. Therefore, in this study, a comparison between the traditional bearing wall systems of blocks and bricks and their structure to this modern structural system was carried out

2. Objective of the research

The main objective of this experimental work is the importance of using the Insulated Concrete Form ICF as an alternative to other traditional systems.

Through this program, the following studies were carried out:

- Studying load and central displacement curves of these systems.
- The effect of EPS on concrete under loading frame.
- Experimental verification of cracks in the ICF system and other system.

3. Literature review

Re-communication with the heritage that is deemed as the embodiment of the conclusions of the practical experience for several generations to solve the problems of design and the integration of modern technology as a way to reach a rich humanitarian synthesis in line with the modern spirit, where many studies are found and their main aim was to overcome those problems of Insulated Concrete Form (ICF). Many studies were carried out to study varies strengthening techniques.

Yokel, (1970), had stressed on another variable that must be considered in styding the wall behavior which is the wall stiffness (EI) the modulus of elasticity decrease with increasing levels of compressive stress.The moment of inertia I, decreased with section cracking.

Yokel and Dikkers, (1971), conducted an investigation that include testing 192 full-scale masonary walls with height up to 20ft (6m) with varible width illustrate the correlation between observed and predicted wall strength showing also the typical stress-strain curves.

Rebert Fisher, (1975), defined the structural walls that make a positive contribution in a structural system showing the behaviour of masonary walls taking into account large number of parameter that effect masonary walls behaviour.

Hamid and Drysdale, (1979), reported the results of axial comperssion tests carried out on 146 concrete bloc prism showing the decrease in morter strength of 69% resulted in acorresponding decrease in prism strength of less than 10%.

Suwalski and Drysdale, (1986) reported the result of an analytical study of the influence of selenderness on the capacity of concrete block masonry walls subjected to an axial compression loads with out of plane eccentricity

Drysdale et. al, (1999), suggested that as a result of the nonlinear of masonary stress-strain curve, the modulus of elasticity can be defined as the chord modulus for a line drawn from the curve at 5% of the maximum compressive strss to 33% of the maximum compressive stress

The U.S. Department of Housing and Urban Development Office of Policy Development and Research Washington, DC November (2001) ICF showing construction costs about three to five percent more than a typical new home and land in today's market (about five to ten percent of house-only construction cost)

Adam J Lohonyai, Yasser Korany and Michael D Ross (2014) studied EFFECT OF INSULATING CONCRETE FORMS IN CONCRETE COMPRESIVE STRENGTH

The tests results are in accordance with the expected behavior (shape of the curve) for continually moisture cure concrete. Concrete keeps gaining strength at a higher rate than non-moisture cured concrete. This is concluded by examining the strength increase plots where concrete and mortar tests gained strength at a higher rate than the wood samples and ICF’s after 28 days. Also, the relation of strength gained after 28 days for continuously moist cure concrete and mortar beyond 28 days is semi-linear.

RDH Building Engineering LTD September (2011) atotal of six ICF wall was tested affixed window was installed assembly for the laboratory air leakage and water penetration test the modification performed has achieved high performance rating.

NAHB Research Center, Inc (2001) [13] studied COSTS AND BENEFITS OF INSULATING CONCRETE FORMS FOR RESIDENTIAL CONSTRUCT

Adam J Lohonyai (2016) [13 evaluated the effectiveness of three different methods to apply closed-cell polyurethane foam to single-wythe concrete masonry wall panels.

Silvio R. Martínez Jerez (2014) [13 seeked to identify if concrete cured in ICF has an effect in compressive strength due to the thermal insulation provided by the forms he was concluded that the ICF affectd concrete strength. It was found that the forms increase concrete strength without the need for additional curing water. An increase of 50% in strength at 56 days was obtained and concluded that the longer concrete cures inside ICF’s, the higher strength it reaches, and that ICF’s effect on concrete strength is proportional to volume of concrete.

Nasim Uddin1 and Wenfeng Du (2014) [13 studied the advantages of beautiful geometrical appearances and efficient structural shapes and he obtained that composite structural insulated panel thin shells have better dynamic performances as the maximum Von-Mises stress is 48.2% less than that of the concrete thin shell under earthquake load.

4. Experimental tests

Experimental program was carried out over eight walls. All walls were fabricated and cured with pure water at suitable site. Four walls from R.C and ICF and other walls from Brick and Cement Block.

4.1 Materials properties

4.1.1. Materials

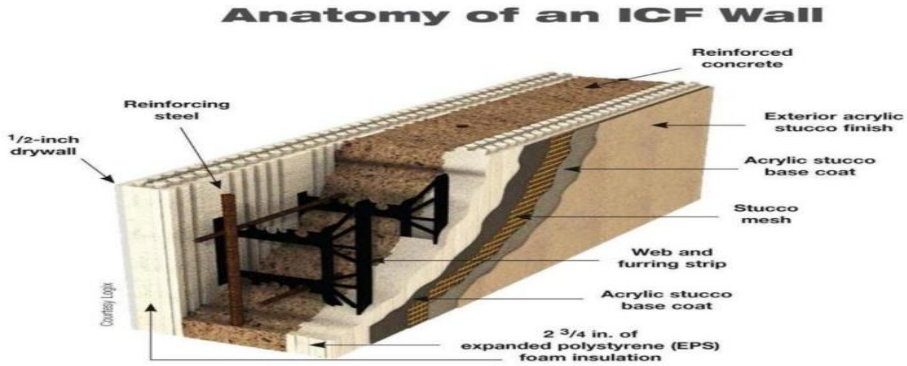
The materials that used in preparation of tested specimens were obtained from local Egyptian sources that are commonly used in Egyptian construction. The mix proportions of concrete were (1:0.78:0.44) for cement: coarse aggregate: fine coarse aggregate: and the water cement ratio was 0.55. Average compressive strength of concrete was 27 MPa after 28 days. Two types of steel reinforcement were used. The first type with grade (28/45) was used with Ø 8 mm diameter as horizontal bars, where the second one which used as vertical bars was Φ10 mm diameter with high-yield strength deformed bars with grade (40/60).

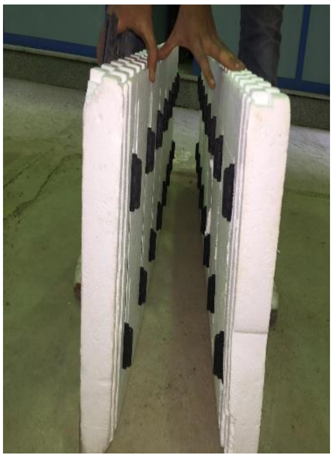
4.1.2. Expanded Polystyrene (EPS)

Production of the modern construction system called Insulation Concrete Form ICF under the commercial name I-BLOCK, with ties of reinforced plastic as a furring strips with dimensions of 120 * 40 cm. Besides the thickness of 6 cm with 8 plastic polypropylene ribs for one sheet with smooth face. Reduces the consumption of air conditioning either for cooling or heating R-Value = 22-46. Additionally, it is characterized by sound insulation as the two layers of foam with a thickness of 12 cm working on increasing the acoustic insulation three times comparing to the traditional buildings. Thus, it provides a quiet environment even in the most crowded places STC = 55-65. Table 1 shows the mechanical properties of EPS sheet block.

Mechanical Properties of EPS Sheet Block

1.	Density	: 6.37 kg/m3 for 60 mm thick EPS Sheet 11.81 kg/m3 for 100 mm thick EPS Sheet
2.	EPS sheets absorbed	more than 80 % of water, when the sample is immersed in water for 24 hours
3.	Compressive Strength:	0.08-0.16 MPa
4.	Cross breaking strength	0.14-0.20 MPa
5.	Tensile Strength	0.3-0.6 MPa
6.	Self-ignition	300 C
7.	Density	6.37,8.25, and 11.81 kg/m^3
8.	Young’s modulus	1.379 x 106 N/m^2
9.	Poisons ratio –	0.1

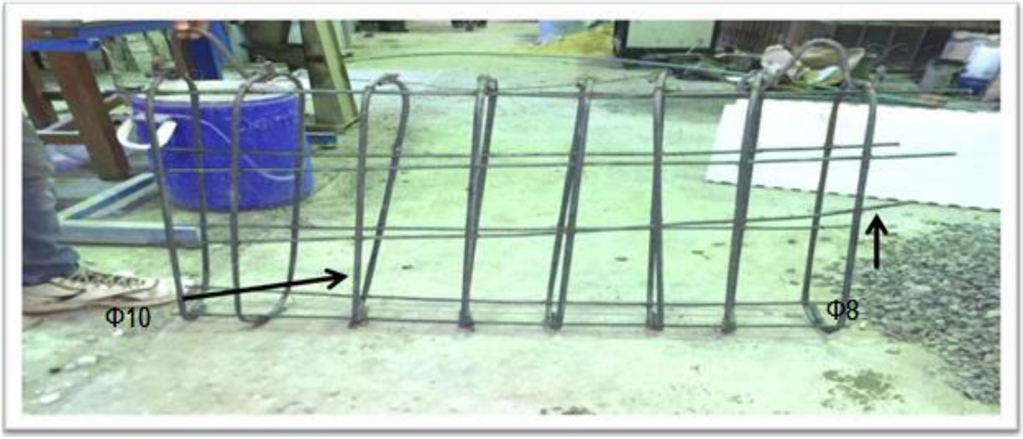




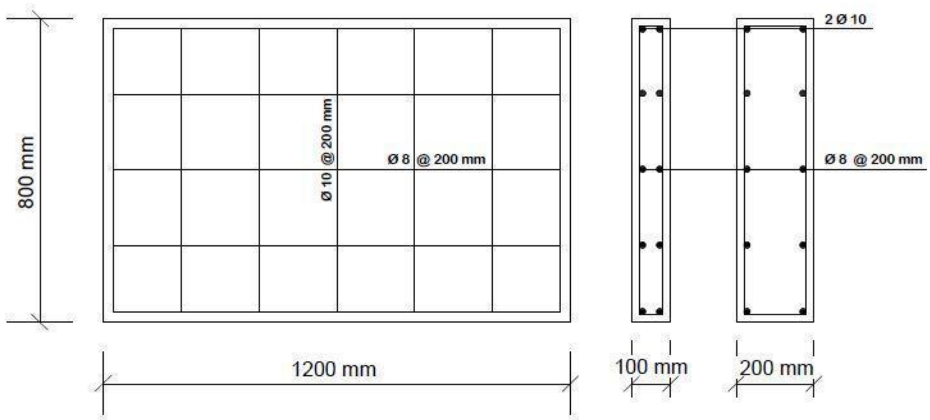
4.2 Test Specimen

Through this experimental program eight wall specimens were cast and tested, which means two walls from each type (brick, block, concrete, and ICF) were prepared. The test specimens were divided into two groups based on the width and type of the wall. The first group consist of four walls from brick, block, reinforced concrete and insulated concrete foams with thickness 100 and the second group. The first group consist of four walls from brick, block, and reinforced concrete and insulated concrete foams with thickness 200 mm as shown in Table 2. Dimensions of the test specimens were 1200 mm length with the overall height of 800 mm. Fig. 1 shows the dimensions, reinforcement detailing, and strengthening schemes of the test specimens.

R.C were considered as control wall, where tow walls of specimens from a new system called I-Block. Specimens were 1200mm length with 1200&800mm effective length classified as two cases, with variable width 100&200mm and the overall depth was 800mm .Two types of steel reinforcement were used. The first type with grade (24/36) was used with 8mm diameter as horizontal, where the second was with grade (36/52) which used with 10mm diameter as a vertical reinforcement. Figure 2 shows the typical dimensions and steel reinforcement layout of the specimens.



Steel reinforcement details



4.3 Test Setup

A total of 8 walls specimens with identical dimension and reinforcement .The total length of the wall was 1200mm. the wall width were 100mm and 200mm respectively with depth 800mm.the other walls of R.C and ICF were tested under single loading point until failure with an effective span of 800 mm using loading frame (5000kn capacity) as shown in figure (1)

using a linear variable central lateral displacement transducer (LVDT) the mid-span displacement was monitored during the test

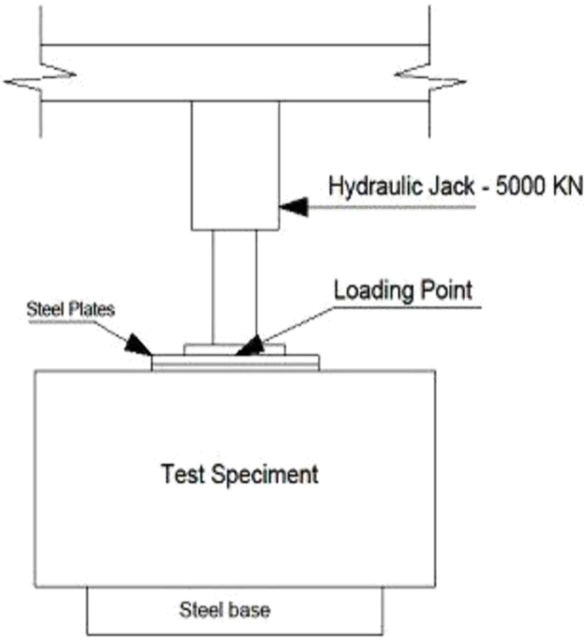


Figure (1): Test Setup

5. Test Results

5.1.1 Cracking Pattern and Mode of Failure

The visible cracks were subsequently marked and photographed after completing the test. Furthermore the digital image correlation processing will also show the formation of the cracks. Fig. 3 shows the failure pattern of the test specimens. The cracks occurred in a symmetrical way on both wall sides. It was observed that for the brick and block walls, the specimens were failed in brittle manner. Vertical cracks due to compression appeared at random points along the height of the walls. These cracks started along the vertical mortar joint, while the horizontal mortar joints showed no signs of any visible damage. For R.C wall was diagonal cracks was appeared from the bottom of the wall to the load and behave as a deep beam. The cracks were increased gradually until the load approached almost its maximum loading. For ICF wall, the EPS sheet above R.C concrete was crushed under the load.
on the complete length of the wall due to
the above mentioned behavior of the wall.

The soft-layer, however was only damaged on the northern end of the wall and shows otherwise almost no signs of deterioration.

After completing the test, it was observed the failure of R.C walls specimens failure can be defined as shear failure. Diagonal cracks were appeared through loading. For other walls vertical cracks appeared under the loading cell. Concrete cracks were seen, and increased gradually until the load approached almost its maximum Figure (2) can tells us the crack patterns

Figure (2) Cracking Pattern and failure mode of the test specimens

Destruction of the upper part under Loading **Identical cracks in EPS sheet block and R.C**

5.2.2 Load Displacement Relationship

After conducting several experiments with the hydraulic press using various specimens of different bearing walls, different results between load and central displacement were found using this kind of bearing walls (Brick-Block-R.C-ICF).Separated by thickness into two different groups 10cm and 20cm.

Discussing the results of the first group (10 cm),

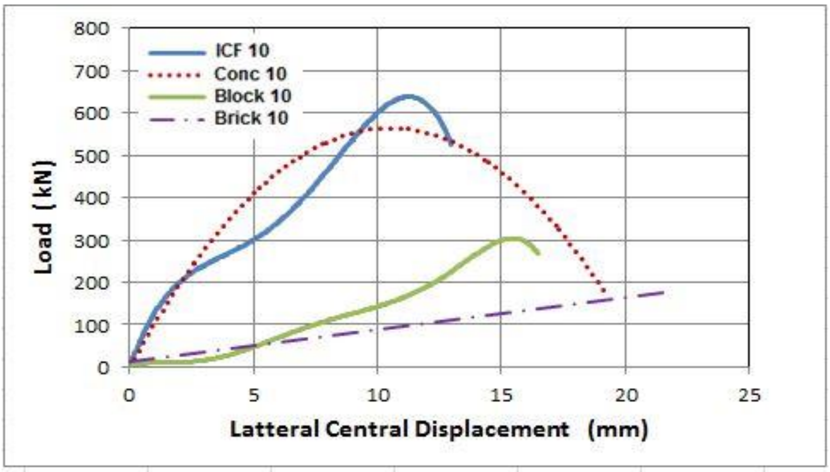


Figure (3)

In the figure (3) above, after pressing the first wall Brick 10, a central displacement was observed upon reaching 170 KN equals to 22 mm. And the wall completely shattered .

Putting the next specimens Block 10 under the same pressing condition, the block wall withstood higher pressure up to 220 KN and central displacement was at 15mm. . And the wall completely shattered at 239 KN.

The R.C10 had a quite noticeable resistance when we used R.C10 up to 400KN of pressure with 8mm of central displacement before showing its first crack. And when increased the pressure to 560 it had a central displacement of 10 mm however, there was an increase of central displacement of 20mm before it finally collapsed.

Using the final bearing wall ICF10 seeing an obvious fluctuation of load pressure on the bearing wall because of the inconsistency of the pressure surface due to the difference in stiffens between the concrete and the EPS sheets. The block withstood a pressure of 620KN with no noticeable crack and a central displacement of 12.5mm. the least amount of all the tested specimens . However, the test had to be stopped because of the aforementioned incontinences.

Discuss now the results of the next group (20cm),

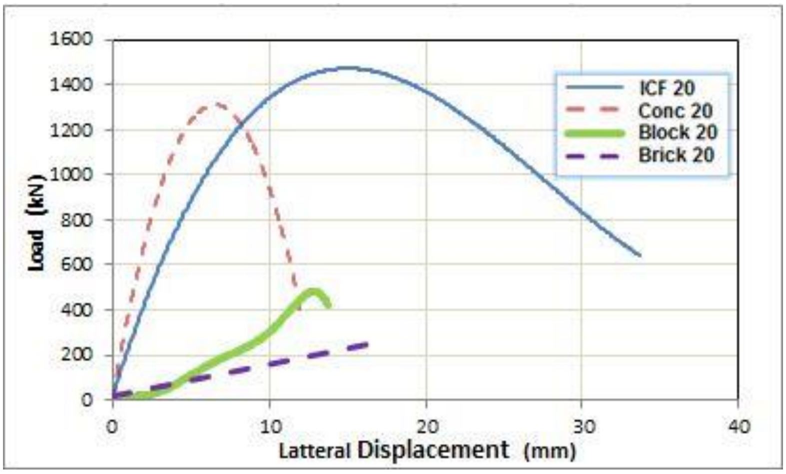


Figure (4)

The figure (4) above, illustrates after pressing the first wall Brick 20, a lateral central displacement was observed at 239 KN equals to 16 mm.

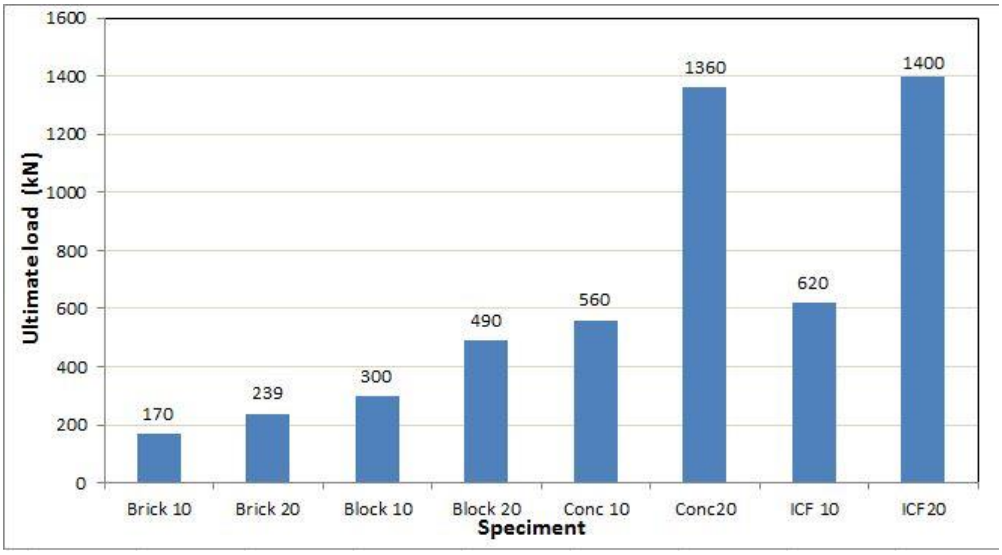
Putting Block 20 and we saw it withstood up to 490KN, and it had a lateral central displacement of 15mm

The R.C20 had quite an astounding resistance to pressure with a result 810 KN before showing its first crack. And when the pressure increased to 1360KN it had a central displacement of 5 mm however, an increase of central displacement of 12mm before it finally collapsed as it was almost double the thickness of R.C10

The final test material which was ICF20 the whole bearing wall withstood the highest amount of pressure among the experimental test walls with a value of 1110KN before a noticeable crack in the upper part appeared with a lateral displacement 8mm approximately however, the wall remained standing while the pressure increased as it was reinforced with ties of plastic furring strips before it finally collapsed at 1400KN with a lateral displacement of 14mm approximately .Although the wall withstood a lot of pressure it had the biggest lateral central displacement of all the tested specimens at 35mm because of the increased length of the plastic ties strips.

5.3. Ultimate Load Capacity

As we can obviously see in the following bar chart the highest material that withstood the loading test was ICF20 with 1400KN, R.C20 came in a close second 1360KN.Brick10 scored the least in the load test with 170KN.



6. Conclusion

The lab experiments have proven that the ICF walls have higher stiffness than the rest of the traditional bearing walls systems “R.C, Block, Brick”, and this evident from the higher resistance of the main loads and the resulting central lateral displacement and cracking from these loads. Where there many previous studies that prove by empirical evidence that the ICF walls are the best option in construction and this is because the ICF is environmentally friendly, can be modified and cost effective alternative method of building.

This study can be concluded and summarized in the following points:

Cracking pattern and mode of failure

R.C 10, 20

The cracks began from below at the part touching the steel base and formed a diagonal pattern then continued upwards until they reached the trass-node area, where they formed a thin vertical line till the part touching the loading jack. The wall as a whole acted as a deep beam.

ICF 10, 20

When testing the ICF20 the vertical cracks appeared from the part touching the loading cell, narrowing as they go down. The reason from this peculiar behavior was the wall had furring strips and plastic binds which prevented the diagonal crack pattern conversely to what happened in ICF10, where the concrete core completely failed without any cracking in the outer layer of the foam. This can be explained because of the short length of the furring strips’ resistance arm which is considered as a flaw. The crack pattern is identical in the foam and concrete and the cracks appear in the concrete and then the foam respectively

The investigation of experimental work on the flexure behavior of walls can be summarized as follows:

1. Using ICF block increase the strength approximately by about 9 % in respect to using specimen R.C 20
2. When the length of the plastic ties furring strips ties increased, the buckling for outer shell of foam increased by 269% so, the max central displacement was in specimens ICF 20

3. Because the increase in strength between R.C and ICF is immaterial it's advisable using it cost-wise
4. Strong ties of web and furring strips don't allow for diagonal cracks in ICF walls specimens where The cracking pattern of the vertically loaded specimens indicated a high stress concentration occurred where there is 16 of furring plastic ties in the specimen.
5. Concrete specimen with EPS sheets show, no cracking or zero crumbling of EPS sheets even after complete failure of concrete core. This indicate when walls are built, they stand and deflect the load even though the carrying concrete has failed.
6. When contrasted with normal plain concrete, the ICF model hasn’t had any noticeable change in the load carrying limit, though when reaching a peak load a sudden failure occurs in the R.C concrete while the ICF exhibits a ductile failure.
7. Because of the utilizing of EPS sheets, formwork is not mandatory while constructing the wall; hence project completion time will be reduced. And it requires minimum skilled labors, becoming cost-effective alternative.
8. Curing process is not needed, since the concrete is covered by EPS sheets.
9. Because of the ductile nature of it, using it may protect the structure from natural disasters like earthquake.
10. Finally the R.C’s crack pattern is similar to the ones in ESP foam insulation

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