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Effect of External Expanded Polystyrene (EPS) Panels on Slabs subjected to Impact Load

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Abstract. The current research addresses the effect of impact load on Reinforced Concrete (RC) slabs strengthened by Expanded Polystyrene (EPS) and/ or Glass Fiber Reinforced Polymer (GFRP) sheets. A total of five slabs were tested; one control specimen without EPS or GFRP, two slabs with two EPS panels with different densities on their impact side, one slab with GFRP sheet on impact side and finally one slab with EPS panel on impact side and GFRP on the tension side. To test the effect of the presence of EPS panels and GFRP sheets, the RC slabs were supported on a table centered below a drop tower. A weight of 3.245 kg was dropped freely from the drop tower to hit the slab. The energy that the slab could withstand was calculated based on the weight, height and number of drops. Results varied according to the variation of parameters; the combination of EPS on the impact side and GFRP on the tension side yielded double the energy the specimen could withstand compared to the control specimen. Results also showed that EPS acted like a cushion that is capable of absorbing a portion of the impact energy. Another finding is that the higher the density of the EPS the more energy it can absorb. This paper proves that EPS is a promising material that could be utilized in reducing the effects of impact loads on concrete structures.

Introduction

Background

Nowadays, not only concrete structures with good quality design, good construction are sufficient to meet the current challenges. It is known that even with good anticipation for any static loads, sudden dynamic loads (winds with strong fixtures, impact knockouts, explosions, rockets and missiles) give rise to a brutal effect on the structure leading to sudden unexpected collapse. The dynamic behavior of the structure, which is subjected to impact load, is very complex and strictly related to the type of the designed structure and the variation of characteristics of each material. Dynamic loading leads to high strain rates and sudden increase in energy that the structure might not be able to withstand in a very short duration. The physical and mechanical response is about the ability of the structure to captivate and discharge the energy directly at this short time interval to the surrounding environment [1].

Objectives

The aim of this paper is to experimentally reach out for materials that could enhance the behavior of concrete structures under impact load. Materials tested in the current work are Glass Fiber Reinforced Polymer (GFRP) sheets and Expanded Polystyrene panels (EPS) with two different densities. Based on the experimental results the energy absorbed due to the utilization of the subject materials can be calculated. In addition to that, results of the current experiment were compared with an experiment previously performed by Hussein (2013) [2], who used the same parameters with different materials, to evaluate the EPS performance.

Relevant Previous Work

Andreas Andersson (2014) tested a total number of 18 slabs. The slabs were made of reinforced concrete and steel fiber reinforced concrete (SRFC). The dimensions of the slabs were 1.75 × 1.75 × 0.12 m. Impact experiments were achieved by dropping a mass of 600 kg of steel. Height of the free falls differed from 1 to 2 m. All the slabs which were subjected to impact load presented a one-way flexural failure, the strength after the impact test was enough to carry the static load of the steel weight. Also, some of slabs showed significant fallout of concrete during impact [3].

A previous study was conducted by Bayoumi et al addressing the effect of impact load on concrete panels . It stated that most of the building facades are made of precast concrete and that the façade is the first layer exposed to external loads. Accordingly, it acts as the first line of defense against any external loads. Two way concrete and ferro-cement slabs were tested having the same dimensions and thicknesses. The results showed that reinforcement significantly influences the overall structure resistance to impact loading; as the amount of reinforcement increases, the load increases indicating a higher section capacity to resist more load and delay cracking and yielding of reinforcement. Results also showed that the location of reinforcement affects the behavior as well [4].

Hussein (2013) [2] used externally bonded Polyurethane (PUR) sheets and GFRP on the impact side to improve the strength of the concrete elements under impact loading. The test consisted of five groups of specimens, first and second groups consisted of five concrete beams each either plain or reinforced concrete with 2φ6 steel bars grade (240/350). Third group consisted of five plain concrete slabs with dimensions 750*580*70 mm and finally the fourth group consisted of the following:

1. The first specimen was used as a control specimen.
2. The second specimen was strengthened using GFRP sheet on the impact side.
3. The third specimen was strengthened using Polyurethane sheets (PUR) on the impact side.
4. The fourth specimen was strengthened using GFRP sheet above a polyurethane sheet (PUR) both on the impact side.
5. The fifth specimen was strengthened using GFRP sheet below a Polyurethane sheet (PUR) both on the impact side.

In the research by Hussein (2013), the group of specimens of interest to the current research was the fourth group. Its results were compared with the current test results.

Experimental Work

Materials Used

Concrete: All the specimens in the test were cast using an identical concrete mixture. Crushed stone with maximum aggregate size of 20mm was sieved, cleaned and washed from dust.
Concrete mix was prepared using the following ratios: Cement (350): Crushed stone (1400): Sand (720): Water (170) in kg per m^3. According to the concrete cubes compressive strength test, the average compressive strength was 28 MPa.

Reinforcing Steel Bars: Slabs reinforcement consisted of 5φ8/m grade (240/350). The steel reinforcement ratio was chosen to approach the lower limit for an under reinforced element.
Expanded Polystyrene: Two sheets of EPS with two different densities were used separately on the impact side or combined with

GFRP sheets. There were no epoxy resin or hardener used to fix the EPS to the slab. The sheet was tested by placing it directly on the slab. **Glass Fiber Reinforced Polymer (GFRP):** GFRP sheets used to strengthen concrete specimens either separately on the impact side or combined with EPS on the tension side of the slab. The supplier of GFRP, Vetrotex, provides two types of GFRP sheets; fibre-mat and woven for reiforcments from E glass rovings. E glass rovings were used in the current test and is commercially known RT 270. Epoxy resin is common for use and commercially known as RENLAM LY113. It was used for GFRP sheets with its hardener commercially known as REN HY97-1 BD.

Specimen Preparation

RC slabs used a mesh of mild steel 5φ8/m in both directions as bottom mesh. Steel cage for RC slabs was manufactured with the required shape and all bars were fixed in place using steel tie wires as it appears in Fig. 1. Before placing the steel cages, wooden forms were painted with oil to ensure easy demolding and form removal process. Steel cages were placed in forms keeping 5mm of concrete clear cover. Digital balance was used to get the actual weight of the mix to ensure that all slabs were manufactured by the same mix ratio. A concrete mixer was used for a suitable mixing period to ensure good and homogenous mixing without segregation. Mixed concrete was placed in the forms as shown in Fig. 2 and a steel rod was used for compaction. In case of specimens with EPS, EPS was just placed on the impact side without epoxy bonding. In case of using GFRP, the GFRP sheets were bonded on the specified surface using epoxy. The epoxy and its hardener were mixed, using the recommended ratio (1000:20) by weight. By a natural-sponge, the mix was spread all over the surface (slab). Then, the GFRP was placed on the wetting until it hardened.

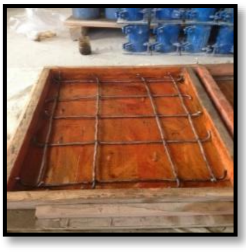

Figure 1 (left) Wooden mold of slab and steel arrangement

Figure 2 (right) Pouring and leveling of concrete

Test Set- Up

The experimental test setup consisted of a steel drop tower, a steel box assembly which the specimens were simply supported on and a 3.245 kg steel cylinder (64mm in diameter) to induce impact load by being dropped on the center of the top surface of each specimen from a 5m height. The impact load was repeatedly applied by dropping the weight of 3.245 kg from the same height of 5m to give the total energy calculated using Eq. 1.

$$m.g.h = 3.245*9.8*5 = 159 \text{ joules} \quad (1)$$

where m: mass (kg), g: gravity (m/s^2) and h: height (m)

Results and Analysis

RC Slab (SR-CONTROL) (Control Specimen). The first flexural crack appeared after the fourth drop on the impact side. It was extended to the bottom side after the seventh drop. Failure of the slab occurred after the ninth drop at the bottom surface. All cracks and failure of specimen can be seen in Fig. 3.

RC Slab Strengthened with EPS on Impact Side (SR-EPS20) Cracks on tension side (bottom side) appeared after the seventh drop. Cracks extended over the bottom surface after the ninth drop. Failure of the slab occurred at the bottom surface after the fourteenth drop. All cracks and failure of the specimen can be seen in Fig. 4.

RC Slab Strengthened with EPS on Impact Side (SR-EPS36) Flexural cracks appeared after the ninth drop at the bottom side of the slab. Failure of the slab occurred at the bottom surface after the twentieth drop. All cracks and failure of the specimen can be seen in Fig. 5.

RC Slab Strengthened with GFRP On Impact Side (SR-GFRP) The flexural crack on its bottom side appeared after the fourth drop. Failure of the slab occurred at the bottom surface after nine drops. All cracks and failure of the specimen can be seen in Fig.6.

RC Slab Strengthened with EPS on Impact Side and GFRP On Tension Side (SR-EPS20-GFRP)

The flexural cracks on the bottom side appeared after the eleventh drop. The following crack appeared and extended over the bottom surface after the thirteenth drop. After sixteen drops a big hole appeared on the impact side and GFRP sheet was about to fail. Failure of the slab occurred at the bottom surface after the eighteenth drop. All cracks and failure of the specimen can be seen in Fig.7.

Figure 3 SR-CONTROL   Figure 4 SR-EPS20

Figure 5 SR-EPS36   Figure 6 SR-GFRP   Figure 7 SR-EPS20-GFRP

Table (1) summarizes the test results, it shows that the failure of the control specimen according to Hussein (2013) occurred after 6 drops while failure of the current test control specimen occurred after 9 drops, this could be the effect of the difference in reinforcement. So, a reduction factor has been calculated and test results were modified accordingly as per Eq. 2.

$$Reduction\ factor = \frac{6}{9} = \frac{2}{3} = 0.667 \quad (2)$$

Endurance is measured by the total number of drops till failure. Figures 8 and 9 present a comparison of maximum drops that caused failure for all tested specimens in the current research and the research by Hussein (2013) as well. Also, Fig. 10 presents the percentage of absorbed impact energy by each specimen relative to the control specimen.

The graphs show a comparison between the specimens along with total number of drops and the total energy to failure in joules *after* multiplying by the reduction factor. All specimens show a substantial increase in impact resistance when strengthened using GFRP, PUR, EPS or combination of PUR and GFRP or EPS and GFRP. Except for the strengthening with GFRP on the impact side does not make any difference in this test while it showed a minor difference according to (Hussein, 2013).

Strengthening with EPS with the lower density (20 kg/m3) sheets at the impact side resulted in the same effect of using both GFRP above PUR sheets on the impact side.

Table 1 Test Results

Test	Specimen Code	Specimen Description	Drop Wt. [Kg]	Drop Ht. [m]	Energy/ drop [J]	Total no. of drops to failure	Total Energy to failure [J]	Total no. of drops to failure (mod.)	Total Energy to failure [J] (mod.)
Current Test Results	SR-CONTROL	without EPS or GFRP	3.245	5	159	9	1431	6	954
Current Test Results	SR-EPS20	EPS (20) on impact side	3.245	5	159	14	2226	10	1590
Current Test Results	SR-EPS36	EPS (36) on impact side	3.245	5	159	20	3180	14	2226
Current Test Results	SR-GFRP	GFRP on impact side	3.245	5	159	9	1431	6	954
Current Test Results	SR-EPS20-GFRP	EPS (20) on impact side and GFRP on tension side	3.245	5	159	18	2862	12	1908
Previous Test Results [2]	SR1	As indicated in text	3.245	5	159	6	954	-	-
Previous Test Results [2]	SR1-C	As indicated in text	3.245	5	159	10	1590	-	-
Previous Test Results [2]	SR1-PUR	As indicated in text	3.245	5	159	12	1908	-	-
Previous Test Results [2]	SR1-C-PUR	As indicated in text	3.245	5	159	10	1590	-	-
Previous Test Results [2]	SR1-PUR-C	As indicated in text	3.245	5	159	22	3498	-	-

Strengthening with EPS panel with higher density (36 kg/m3) at the impact side was more effective than using GFRP sheet only on the impact side in all specimens.

Also strengthening with EPS panel with higher density (36 kg/m3) at the impact side was more effective than using PUR sheet only on the impact side in all specimens.

Strengthening with EPS panel with higher density (36 kg/m3) at the impact side was more effective than using both GFRP above PUR sheets on the impact side.

Using both GFRP on tension side and the EPS panel with density 20 kg/m3 on the impact side is way more effective than using both GFRP above PUR sheets on the impact side.

While using PUR above GFRP is more effective than any of the tested specimens even the one which had EPS on the impact side and GFRP on the tension one. However, it should be taken in consideration that the EPS panel used in this combination was the one with lowest density (20kg/m3). So, if the panel with higher density was used, the result could be different.

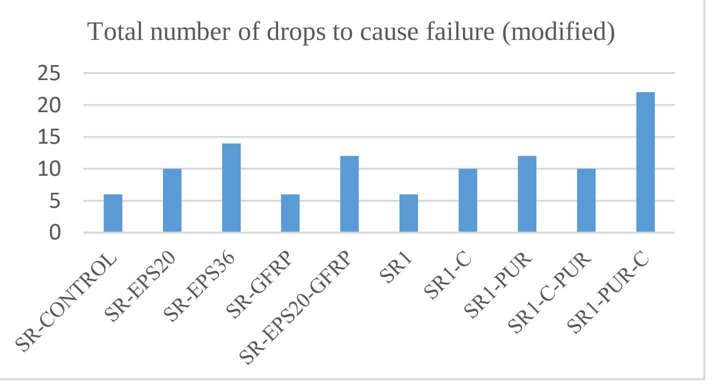

Figure 8 number of drops to cause failure for the slabs (modified) after reduction

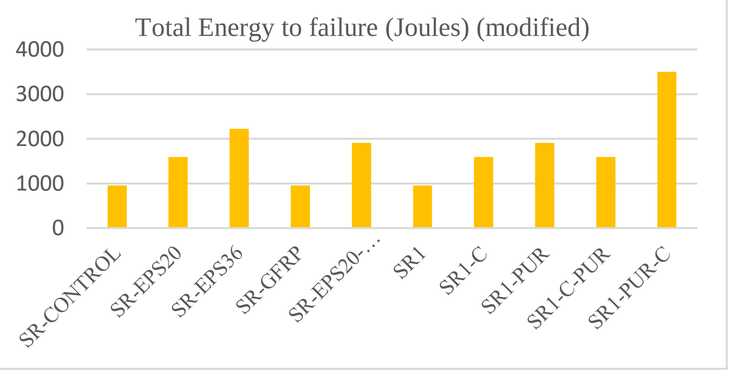

Figure 9 Amount of energy in joules to cause failure for the slabs (modified)

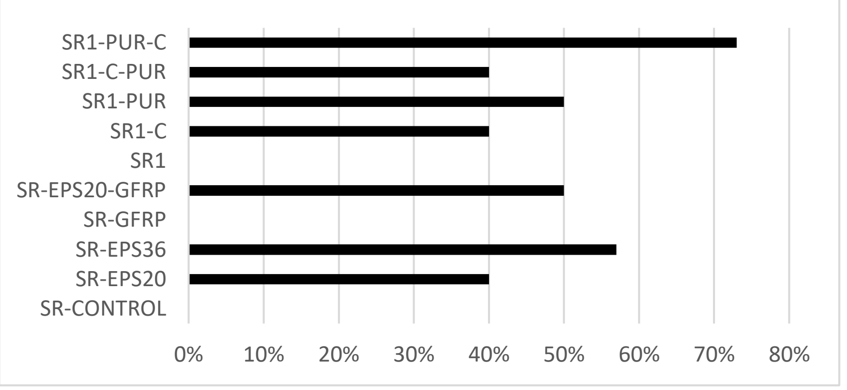

Figure 10 Percentage energy absorbed relative to the control specimen

Conclusions

There are tremendous challenges for structural engineers to repair existing concrete structures especially with the increase in threats that could cause unexpected dynamic loads. EPS is a promising material in terms of its energy absorption capability [5]. Also, using it with GFRP proved to be effective especially when it was pasted on the tension side of the slabs.

According to the tests performed, the following points were concluded:

1. GFRP and EPS sheets significantly increased the ultimate loading carrying capacity of concrete slabs in resisting impact load.
2. Using GFRP is not effective if used to absorb impact energy yet it proved to be effective in strengthening the tension side.
3. Using EPS with two different densities 20 kg/m3 and 36 kg/m3, increased resistance to impact by 40% and 57% respectively relative to the control specimen.
4. Using EPS with density 20 kg/m3 on the impact side resulted in the same results of using both GFRP above PUR sheets on the impact side.
5. Using EPS with density 36 kg/m3 on the impact side is more effective than using either GFRP or PUR sheets only on the impact side in all specimens.
6. Using both GFRP on tension side and EPS with density 20 kg/m3 sheets on the impact side increased resistance to impact by 50% relative to the control specimen.
7. Using both GFRP on the tension side and EPS with density 20 kg/m3 sheets on the impact side is more effective than using both GFRP above PUR sheets on the impact side.

8. Using both PUR above GFRP on the impact side is more effective than using both GFRP on tension side and EPS with density 20 kg/m^3.

Expanded Polystyrene proved to act as a “cushion” that absorbs a relatively big portion of the impact energy. EPS is a light and easy to handle material. Results of this paper showed that this material has good potential in absorbing energy and is effective when used on concrete structures prone to impact loads.

Recommendations

1. Use epoxy and hardener in any EPS experimental test to be more effective and achieve more accurate results.
2. Study the effect of using EPS with higher densities either with GFRP or CFRP sheets on tension side and compare the results with competitive strengthening materials.

References

1. Zhan, T., Wang, Z. and Ning, J. (2015). *Failure Behaviors Of Reinforced Concrete Beams Subjected to High Impact Loading.* Engineering Failure Analysis (56).

2. Hussein, M. M. (2013). *Behavior of Concrete Beams and Slabs Strengthened with Composite Laminates and Polyurethane Sheets under Impact Loading.* Masters Thesis at the British University in Egypt.

3. ANDERSSON, A. (2014). *Impact Loading On Concrete Slabs: Experimental Tests And Numerical Simulations.* Report 153 by the Civil and Architectural Egineering Department of the Royal Institute of Technology (KTH), Stockholm, Sweden.

4. Bayoumy, H.G.S, Abdel-Mooty, M. A. N. and Ezeldin, A. S. (2015) *Experimental evaluation of concrete panels under impact loading.* Proceedings of the Second International Conference on Performance-based and Life-cycle Structural Engineering (PLSE 2015). School of Civil Engineering, The University of Queensland, pp 1373-1381.

5. Hu, Z., Xu, J., Peng, G. and Cao, S. (2010). *Energy-Absorption Property of Expanded Polystyrene Concrete under Impact*. Kuei Suan Jen Hsueh Pao/Journal of the Chinese Ceramic Society (38) pp. 1173- 1178.