

Original Article

Impact Resistance Analysis of Fibre Reinforced Concrete for Application in Dynamically Loaded Spillways and Other Hydraulic Structures

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Abstract - Spillway and regulating structures of large dams are increasingly subjected to severe impact loading due to extreme hydrological events such as cloudbursts, sudden reservoir releases, and high-velocity flows. These conditions cause progressive surface deterioration, cracking, and loss of serviceability of conventional concrete. Traditional concretes with their intrinsic compressive strength and limited tensile strength have been used for the construction of these hydraulic structures, with limited resistance to impact/dynamic loading. In this study, the effectiveness of Fibre Reinforced Concrete (FRC) in enhancing the impact resistance of spillway-grade concrete is experimentally investigated for adoption under these dynamic load conditions. Adoption of FRC will help in reducing the recurring repair costs on account of damage to hydraulic structures under dynamic impact loading conditions. Concrete mixes of grades M20, M25, and M30, commonly used in hydraulic structures, were prepared with three different types of fibres, namely Plain Steel Fibres, Hooked-End Steel Fibres, and Polypropylene Fibres, at varying dosage levels. Impact resistance was evaluated using the ACI Committee 544 drop-weight impact test, in which a 44.48 N hammer was repeatedly dropped from a height of 457 mm onto disc-shaped concrete specimens until cracking and ultimate failure occurred. The impact energy was calculated from the number of blows required to initiate cracking and to reach final failure. The test results show that fibre inclusion significantly improves both the crack resistance and the ultimate impact energy absorption of concrete. Among the fibres studied, hooked-end steel fibres exhibited the greatest improvement, owing to their superior mechanical anchorage and bond with the cement matrix. Higher-strength concrete (M30) demonstrated greater impact resistance, indicating that improved matrix strength enhances fibre effectiveness. Polypropylene fibres, despite their low density and small dosage by weight, produced substantial improvement in impact resistance due to their high fibre count and crack-bridging ability. However, for all fibre types, the rate of increase in impact resistance reduced beyond optimum fibre content. The study confirms that fibre reinforced concrete, particularly with hooked-end steel fibres and optimized polypropylene fibre content, provides a robust and economical solution for improving the durability and impact resistance of spillways and regulating structures exposed to severe hydraulic loading.

Keywords - Dynamic Impact Loading, Impact Energy, Fibre Reinforced Concrete, Fiber Volume, Grade of Concrete, Drop Hammer Test.

1. Introduction

This study was carried out after an unprecedented magnitude of inflows. In particular, cloudburst incidents in the hilly terrain of Himachal Pradesh have resulted in excessive and sudden inflows into downstream reservoirs, thereby levying severe dynamically induced hydraulic impact loads on dams and associated regulating and storage structures. In response to these damages, multiple technical deliberations were undertaken to identify suitable material additives capable of enhancing the impact resistance of concrete to a reasonable extent. Various types of fibres available in the market were considered, and laboratory tests were conducted to evaluate their performance. These tests focused on determining the most

appropriate type and dosage of fiber for use in the repair and rehabilitation of the damaged concrete structures. The research involved an extensive review of relevant literature, including published research papers, as well as controlled laboratory experiments.

Based on the combined outcomes of theoretical understanding and experimental validation, the study aimed to narrow down the selection of fibre type and their dosage to ensure effective improvement in impact resistance and durability of the repaired concrete under severe hydraulic loading conditions. Hence, concrete must have adequate resistance to impact and impulsively applied loads. Given that concrete is a brittle, stress-rate-sensitive



material, a special consideration of these characteristics in the design of structures subjected to impact load is essential.

As the relatively low tensile strength and fracture energy of concrete result in poor impact resistance, much research has been directed towards developing materials that exhibit better impact resistance than concrete. Fibre-reinforced concrete has emerged as a viable structural material for use in such instances.

The use of steel-reinforced concrete in hydraulic structures is an essential requirement. The present study is aimed at the application of fibre reinforced concrete in the hydraulic structures, especially spillways, which are subjected to dynamic/ impact loading.

This study is aimed at adopting concrete that is less susceptible to damage owing to dynamic impact loading due to changing weather conditions and sudden ingress of water in the hydraulic structures, such as dams, head works, and spillway structures. These structures of national importance need careful usage of tried and tested material for achieving longevity and sustainability, so recycled material is not considered for use, and materials with proven, documented behaviour and with dependence levels have been used.

2. Literature Review

The studies have been carried out worldwide to ascertain the effect of dynamic loading inducing impact upon the hydraulic structures such as dams, spillways, and other head regulators. There is extensive data available to gauge the impact of loading due to water inflows on these structures and their detrimental effect. The concrete dam spillway and other hydraulic structures play a critical role in the management of Canal water flows and distribution, and are instrumental in mitigating the potential flow in flood or sudden influx of water due to various other reasons [1]

The flowing water induces an impact on account of mechanical energy converted to impact, and this effect is modulated by a factor dependent upon flow velocity, depth of water, and turbulence [2].

The FRC has been employed by various researchers in mitigating the effect of abrasive inflows. Concrete abrasion resistance improves with a lower water–cement ratio and higher strength, while polypropylene fiber reinforcement further enhances resistance to abrasive erosion. [3]. There are other additives used for increasing the abrasion and impact resistance of concrete [4, 5].

Various studies have been carried out worldwide to gauge the erosion of concrete in Hydraulic Structures [6], which has led to the development of methodologies/ procedures devised by various researchers/ reputed organizations that are accepted worldwide and are used for ascertaining the Impact resistance [7, 8].

3. Methodology

3.1. Techniques for Impact Resistance Measurement [7,8]

The test used for measuring impact resistance is as per the recommendations of the ACI Committee 544, which is an internationally accepted testing methodology. The test is to be carried out 26 by dropping a hammer weighing 44.48 N (10 Pounds) from a height of 457 mm (18”) repeatedly on a 63.5 mm diameter hardened steel ball, which is placed on the top of the centre of a 150 x 63.5 mm cylindrical concrete specimen (disc) as shown in Fig. 1. The steel ball is free to move vertically within a 63.5 mm cylindrical sleeve.

The test should continue until complete failure. For each specimen, the number of blows required to cause a visible crack and to propagate cracks until ultimate failure should be measured. The ultimate failure is declared when the cracked test specimen touches the steel lugs located at a 5 mm distance from the specimen due to the impact energy supplied by the dropped hammer. The results can be evaluated on the basis of averaging the obtained values. Five specimens are recommended for replication. The highest and lowest values should be discarded, and the impact resistance is the average of the remaining three [9].

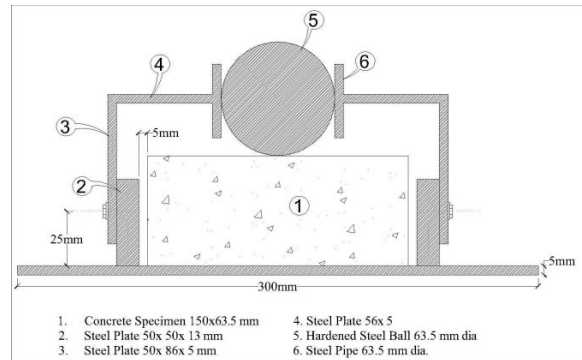


Fig. 1 The sample placement for the Impact Resistance test

$$\text{Impact Energy [10]} I_E = (0.5 \times m \times V^2) \times n \quad \text{-- A}$$

Where m = Mass of hammer; V= Impact Velocity, and n= Number of Blows

$$\text{The Height of the Hammer fall is } H = (g \times t^2)/2 \quad \text{-- B}$$

where g is the acceleration due to gravity = 9810 mm/sqSec; t is time in seconds required for the fall of the hammer from a height of 457 mm.

$$V = g \times t \quad \text{-- C}$$

$$m = W/g, \text{ i.e., Weight/ acceleration due to gravity.} \quad \text{-- D}$$

With H =457mm, g=9810 mm/sqsec, the value of t comes out to be 0.3052 Seconds

$$V \text{ (From equation C)} = 9810 \times 0.3052 = 2994.01 \text{ mm/s}$$

From equation A, the Impact Energy

$$I_E = (0.5 \times 44.48 \times 2994.012) / (9810 \times 1000)$$

$$= (20.32 \times n) \text{ KN-mm}$$

3.2. Mix Design Used For Test Samples

The mix designs adopted for spillway construction are generally M20, M25, and M30, so the mix design for these

has been done as per the codal procedure IS:10262-2019 [11]. The fibres used in these mixes are as per Table 1. The geometry and volume of fibres used are after perusal of various research carried out by other researchers [12, 13, 14, 15,16].

Table 1. The details of fibres used for preparing Fibre Reinforced Concrete.

Code	Fibre Material	Fibre Geometry	L mm	Dia mm	Density (g/cm ³)	Tensile Strength (MPa)
F1	Steel	Plain	60	0.8	7.84	1050
F2	Steel	Hooked End	60	0.8	7.84	1050
F3	Polypropylene	Plain	50	--	0.91	550

Three-number mix designs with 3 kinds of fibres in different proportions have been prepared to check the

samples. The final mix designs for the study are brought under Table 2.

Table 2. Mix Design for the test samples

	UoM	M20 Grade Concrete	M25 Grade Concrete	M30 Grade Concrete
Cement (PPC)	Kg	315	345	385
Fine Aggregate	Kg	640	635	625
Coarse Aggregate (10mm)	Kg	675	670	650
Coarse Aggregate (20mm)	Kg	590	585	575
Water	Kg	155	148	130
F1 Fibre 0.5%	Kg	11.88	11.92	11.83
F1 Fibre 1.0%	Kg	23.75	23.83	23.65
F1 Fibre 1.5%	Kg	35.63	35.75	35.75
F2 Fibre 0.5%	Kg	11.88	11.92	11.83
F2 Fibre 1.0%	Kg	23.75	23.83	23.65
F2 Fibre 1.5%	Kg	35.63	35.75	35.75
F3 Fibre 0.5Kg/Cum	Kg	0.5	0.5	0.5
F3 Fibre 1.0 Kg/Cum	Kg	1.0	1.0	1.0
F3 Fibre 1.5 Kg/Cum	Kg	1.5	1.5	1.5
Superplasticizer	Kg	6.3	6.9	7.7

The tests have been performed as per the recommendations of the ACI Committee 544 [7].

4. Results And Discussion

The 5 samples for each Mix Grade and each Fibre type/content have been prepared. Thus, the total number of samples prepared is $5 \times 3 \times 3 \times 3 = 135$ samples. For each set

of 5 samples, the highest and lowest values are discarded, and the impact resistance is the average of the remaining three. The number of blows required for the initial crack, the number of blows required for final failure, and the corresponding Impact Resistance have been calculated for each set of samples. The results so obtained are enumerated in Table 3.

Table 3. Results of Impact tests

Mix Design	Fibre Type and Dosage	Number of blows for Initial Crack	Impact Resistance (KN-mm)	Number of Blows for Final Crack	Impact Resistance (KN-mm)
M20	No Fibre	14	284.48	23	467.36
	F1 Fibre 0.5%	72	1463.04	110	2235.20
	F1 Fibre 1.0%	120	2438.40	161	3271.52
	F1 Fibre 1.5%	146	2966.72	210	4267.20
	F2 Fibre 0.5%	74	1503.68	116	2357.12
	F2 Fibre 1.0%	124	2519.68	171	3474.72
	F2 Fibre 1.5%	153	3108.96	221	4490.72
	F3 Fibre 0.5Kg/Cum	60	1219.20	78	1584.96

	F3 Fibre 1.0 Kg/Cum	101	2052.32	131	2661.92
	F3 Fibre 1.5 Kg/Cum	128	2600.96	165	3352.80
M25	No Fibre	18	365.76	25	508
	F1 Fibre 0.5%	92	1869.44	120	2438.40
	F1 Fibre 1.0%	138	2804.16	185	3759.2
	F1 Fibre 1.5%	186	3779.52	246	4998.72
	F2 Fibre 0.5%	95	1930.40	126	2560.32
	F2 Fibre 1.0%	142	2885.44	190	3860.80
	F2 Fibre 1.5%	195	3962.40	253	5140.96
	F3 Fibre 0.5Kg/Cum	76	1544.32	89	1808.48
	F3 Fibre 1.0 Kg/Cum	127	2580.64	141	2865.12
	F3 Fibre 1.5 Kg/Cum	149	3027.68	170	3454.40
M30	No Fibre	23	447.04	31	629.92
	F1 Fibre 0.5%	118	2397.76	148	3007.36
	F1 Fibre 1.0%	171	3474.72	199	4043.68
	F1 Fibre 1.5%	236	4795.52	289	6116.32
	F2 Fibre 0.5%	122	2479.04	156	3169.92
	F2 Fibre 1.0%	211	4287.52	259	5262.88
	F2 Fibre 1.5%	245	4978.04	301	6299.20
	F3 Fibre 0.5Kg/Cum	98	1991.36	110	2235.20
	F3 Fibre 1.0 Kg/Cum	157	3190.24	179	3637.28
	F3 Fibre 1.5 Kg/Cum	191	3881.12	212	4307.84

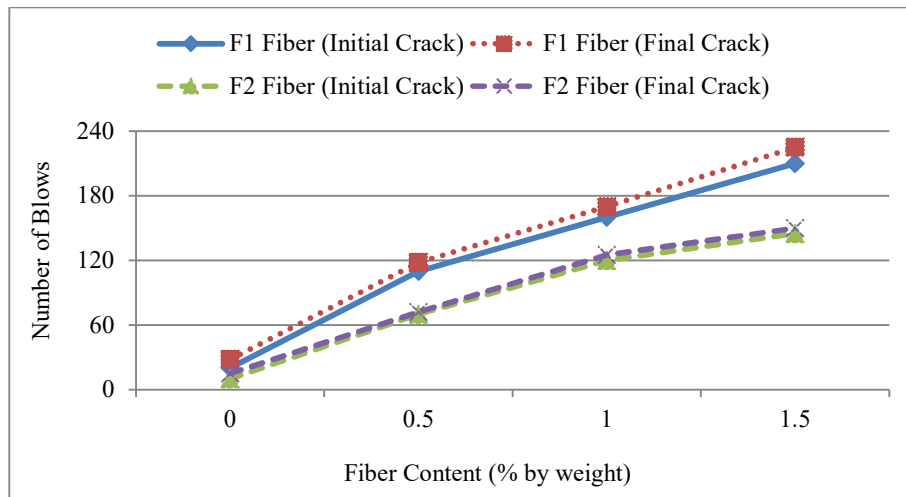


Fig. 2 Impact Resistance of M20 Grade Concrete with Steel Fibre

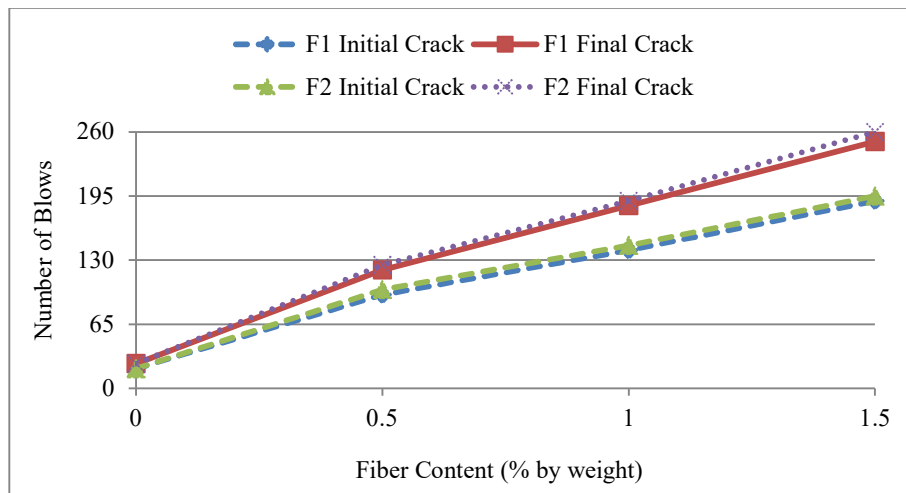


Fig. 3 Impact Resistance of M25 Grade Concrete with Steel Fibre

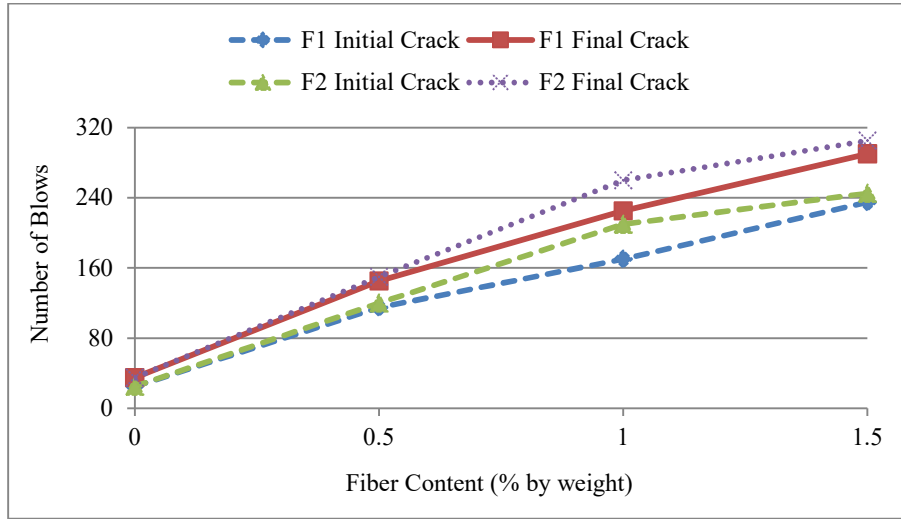


Fig. 4 Impact Resistance of M30 Grade Concrete with Steel Fibre

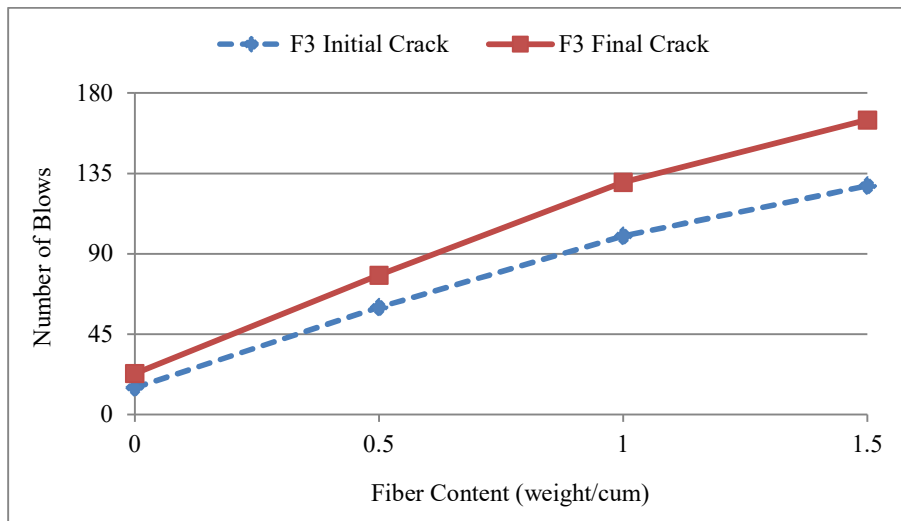


Fig. 5 Impact Resistance of M20 Grade Concrete with Polypropylene Fibre

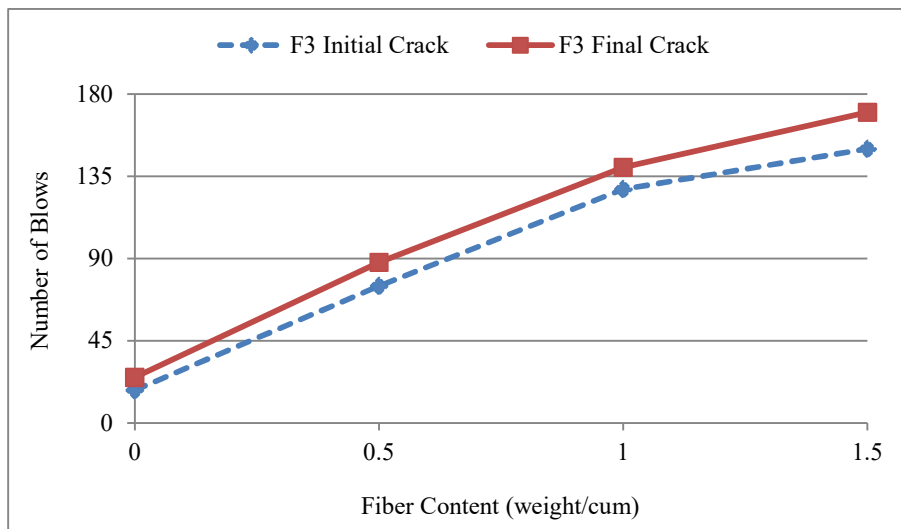


Fig. 6 Impact Resistance of M25 Grade Concrete with Polypropylene Fibre

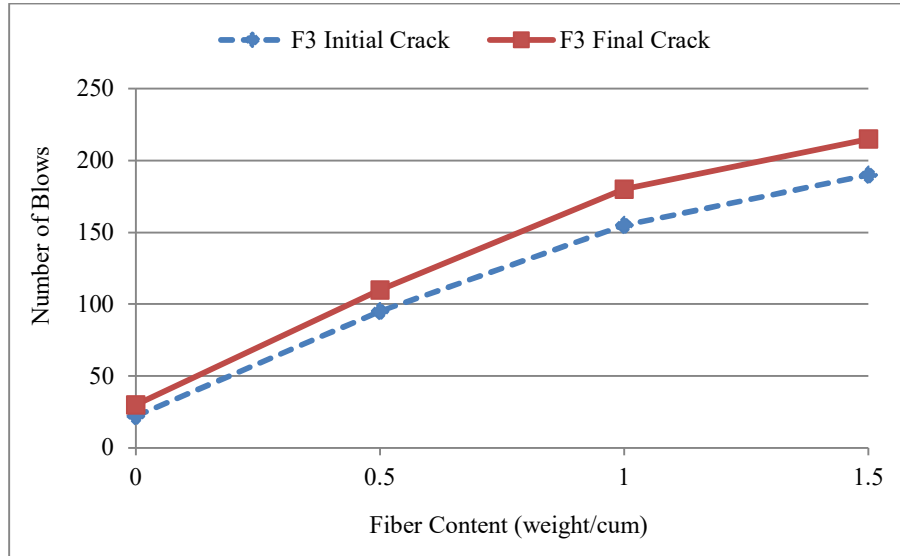


Fig. 7 Impact Resistance of M30 Grade Concrete with Polypropylene Fibre

Perusal of the test results, the graphs Figure II to Figure VII are plotted to check the behavior, and the following is observed:

1. The addition of fibres gives a substantial increase in the resistance against impact loading engineering characteristics, and fibre reinforced concrete can sustain higher impact and will result in less deterioration of concrete.
2. For steel fibres, the fibres with hooked ends perform better; this is due to the proper bond created between steel fibres and the concrete
3. As the strength of concrete is increased, the resistance against impact loading increases substantially. This is not only due to an increase in the strength of concrete but is corroborated by the fact that the increase in strength of concrete lead to better bond between concrete and fibres which makes the fibre inclusion more effective.
4. For all types of fibres the initial rate of gain in Impact resistance is more and the rate of increase subsidises on increasing the fibre content.
5. For steel fibres with higher grade of concrete, M30, resistance against initial crack and final failure increases substantially with 1% addition, whereas the effect is not that discernable for fibre addition beyond that.
6. For Polypropylene fibres the increase in Impact resistance is substantial till 1 Kg/Cum addition and thereafter the rate of increase in impact resistance decreases.
7. The small addition by weight of Propylene fibres gives immense increase in Impact resistance vis-à-vis the fibre addition by weight of steel fibres. This is due to the fact that density of propylene fibre is substantially less than that of steel fibres which means lot more fibre addition with same addition of weight.

5. Conclusion

The fibres are considerably effective in increasing the Impact resistance capacity when added to the plain concrete. Although the Steel fibres perform better than the polypropylene fibres and steel fibres with hooked ends performing best but the polypropylene fibres added in less weight gives better results vis-a vis the steel fibres.

For polypropylene fibres, the results are best for 1.0% fibre content which comes out to be optimum fibre content with techno-economic criteria.

Due to considerable increase in Impact resistance capacity of Fibre Induced Concrete against dynamically induced impact loading. The addition of 1kg/cum of polypropylene fibre is optimum from techno-economic analysis for the resistance offered against impact loading.

The findings may give beneficial results in repair and rehabilitation of damaged spillway and other components of hydraulic structures.

Consequently, the adoption of these methods in hydraulic structures, including spillways and gates experiencing high-impact water loads, offers considerable potential for improved structural capacity against dynamic impact loading.

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References

- [1] Nur Azwa Muhamad Bashar et al., "Hydraulic Properties of Flow Over Different Types of Spillways: A Review," *Proceedings of AWAM International Conference on Civil Engineering 2022 - Volume 3, AICCE, Sustainability and Resiliency*, Singapore, vol. 386, pp. 683-696, 2024. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [2] Qiong Liu et al., "Abrasion Damage of Concrete for Hydraulic Structures and Mitigation Measures: A Comprehensive Review," *Construction and Building Materials*, vol. 422, pp. 1-25, 2024. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [3] Zoran J. Grdic et al., "Abrasion Resistance of Concrete Micro-Reinforced with Polypropylene Fibres," *Construction and Building Material*, vol. 27, no. 1, pp. 305-312, 2012. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [4] B.L. Rajput, and S.S. Pimplikar, "Abration and Impact Resistance of Concrete Produced with Nano-Silica," *Materialstoday: Proceedings*, vol. 59, no. 1, pp. 115-119, 2022. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [5] Yu-Wan Liu, "Improving the Abrasion Resistance for Hydraulic-Concrete Containing Surface Crack by Adding Silica Fume," *Construction and Building Material*, vol. 21, no. 5, pp. 972-977, 2007. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [6] James R. Graham et al., "Erosion of Concrete in Hydraulic Structures," ACI Committee 210 Report, pp. 1-24, 1998. [[Google Scholar](#)]
- [7] Americal Concrete Institute, ACI PRC-544.9-17: Report on Measuring Mechanical Properties of Hardened Fiber-Reinforced Concrete, 2017. [Online]. Available: https://www.concrete.org/store/productdetail.aspx?ItemID=544917&Language=English&Units=US_AND_METRIC
- [8] Atef Badr, and Ashraf Ashour, "Modified ACI Drop-Weight Impact Test for Concrete," *ACI Materials Journal*, vol. 102, no. 4, pp. 249-255, 2005. [[Google Scholar](#)] [[Publisher Link](#)]
- [9] Ernest K. Schrader, "Impact Resistance and Test Procedure for Concrete," *ACI Materials Journal*, vol. 78, no. 2, pp. 141-146, 1981. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [10] K. SaiAbhinav et al., "Research on Impact Resistance of Fibre Reinforced Concrete," *International Journal of Innovative Technology and Exploring Engineering*, vol. 8, no. 6S4, pp. 295-298, 2019. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [11] IS0262:2009, "Concrete Mix Proportioning-Guidelines (First Revision)," Bureau of Indian Standards, New Delhi, 2009. [[Google Scholar](#)]
- [12] Wasim Abbass, M. Iqbal Khan, and Shehab Mourad, "Evaluation of Mechanical Properties of Steel Fiber Reinforced, Concrete with Different Strengths of Concrete," *Construction and Building Materials*, vol. 168, pp. 556-569, 2018. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [13] Ahmet B. Kizilkanat et al., "Mechanical Properties and Fracture Behavior of Basalt and Glass Fiber Reinforced Concrete: An Experimental Study," *Construction and Building Materials*, vol. 100, pp. 218-224, 2015. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [14] Mujeeb Rahman Latifi et al., "Effect of the Addition of Polypropylene Fiber on Concrete Properties," *Journal of Adhesion Science and Technology*, vol. 36, no. 4, pp. 345-369, 2022. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [15] Khin T. Soe, Y.X. Zhang, and L.C. Zhang, "Material Properties of a New Hybrid Fibre-reinforced Engineered Cementitious Composite," *Construction and Building Materials*, vol. 43, pp. 399-407, 2013. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [16] Shin Hwang, Pey-Shiuan Song, and Bor-Chiou Sheu, Impact Resistance of Polypropylene Fiber- Reinforced Concrete, Research Gate, 2003. [Online]. Available: https://www.researchgate.net/publication/239544915_Impact_Resistance_of_Polypropylene_Fiber-Reinforced_Concrete