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Prediction of Load Capacity Reduction of RC Beam and Slab Connection with Cold Joints Using a Combined Approach of Back propagation Neural Network for Non-Destructive Testing and ANSYS Simulation

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Abstract:
This research paper outlines a proposed methodology for predicting load capacity reduction in reinforced concrete (RC) beam and slab connections with cold joints. The topic addresses a significant concern in structural engineering. Cold joints typically appear during construction and pose a great risk to the structural integrity of a building, thus necessitating accurate prediction. To study this issue comprehensively, actual samples of beam and slab connections with cold joints were formed with extreme care under NSCP 2015 and ACI provisions. These samples underwent complex testing using an ASTM C78/C78M Three-Point Loading Testing Machine. Testing was conducted on samples with and without cold joints to provide criteria for comparison. In an effort to solidify the findings, a comprehensive analysis was conducted considering several contributory factors. Factors such as the time of pouring and curing, the angle of inclination of cold joints, surface position, and type of adhesive were all seriously considered. This multifaceted approach provided a deep understanding of the complex interplay between these variables and the resulting load capacity reductions. The integration of a BPNN trained on non-destructive testing data with ANSYS simulation facilitated insights into structural behavior under diverse conditions. The artificial intelligence BPNN model, developed from empirical data obtained from actual testing, accurately predicted both the flexural strength and deflection of the sample beam and slab connections. It also provided insights into the intricate mechanisms of load capacity reduction. By combining machine learning with finite element analysis, this methodology advanced the understanding of load capacity reduction in RC structures with cold joints. This allows engineers to make informed decisions on design changes and retrofitting strategies to produce safer and more resilient infrastructure systems.

Keywords **—load capacity reduction, reinforced concrete beam and slab connections, coldjoints, structural engineering, Backpropagation Neural Network (BPNN), ANSYSsimulation, finite element analysis**

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I. INTRODUCTION

In the field of structural engineering, the strength and stability of an infrastructure system depended on the strength and load-carrying capacity of the reinforced concrete beams and slabs. Cold joints were, in fact, one of the most prevalent problems concerning the concrete pouring process. This tendency was a significant reason for concern, as it could cause insufficient structural performance. The research was conducted to precisely estimate the reduction in load capacity at the connections of reinforced concrete beams and slabs affected by cold joints, in order to provide a non-destructive testing method.

Cold joints introduced hidden weaknesses in the structure, which were not easily visible but became evident under operational loads. Therefore, this process of prediction and evaluation played a crucial role in determining the effect of cold joints on the load carrying capacity of a structure. In most cases, such methods were not useful since they could hardly evaluate the effect of cold joints. The bond strength at the interface was weakened, thus reducing the load-bearing capacity and risking safety and possible structural failures. Not only did cold joints present functional problems, but in most cases, they also resulted in aesthetically poor and displeasing finished structures. The paper developed a unified framework for assessing and mitigating the effects of cold joints in reinforced concrete connections. Through the use of advanced technology and innovative modeling strategies, this study aimed to provide valuable results for both engineers and practitioners, enabling them to confidently apply this knowledge to practical applications for the safe and reliable operation of concrete structures.

Cold joints, whether intended or unforeseen, were unavoidable in the construction industry, particularly in the context of concrete structures. The study focused on the influence of cold joints on the flexural strength of a beam. Cold joints were halting points in the concrete casting process that were required due to the impracticality of casting concrete in one continuous operation. The concrete quantity produced in a tone time was governed by the capacity of the mixer and the strength of the formworks. As a result, the concrete casting process could be interrupted and resumed multiple times, resulting in the initiation of building joints [1].

Cold joints could be found in major constructions such as bridges, dams, above water tanks, and buildings with extensive concreting. The delay in concreting was caused by labor shortages, a lack of adequate equipment, poor site organization, insufficient work scheduling, low labor efficiency, and equipment breakdown during mass building, resulting in the creation of cold joints. Cold joints were planes of failure generated by casting practice disturbances that altered structural behavior. Because cold joints had already formed in such circumstances, caution had to be exercised while concreting the fresh mix with set concrete. It was common to witness concreting without cold joint treatment on various building sites. Because cold joints in concrete were a form of crack in concrete, they could cause further crack growth and structural collapse in the future [2].

Figure 1. Cold Joint on Reinforced Concrete Structure

II. METHODOLOGY

In the methodology chapter, a systematic approach was outlined to address the research question effectively, ensuring the validity of the study's findings. The chapter meticulously detailed the research methods employed, including the selection of appropriate data collection procedures and analytical techniques. Each step of the research process was carefully explained, from the initial design of experiments to the final analysis of results. This thorough documentation not only facilitated replication of the study by other researchers but also ensured the accuracy and reliability of the findings. By adhering to a structured methodology, the study was able to maintain rigor and transparency, enhancing the credibility of its conclusions.

2.1 Research Instrument

The researchers used various analytical and structural tests as research instruments to gather the appropriate data needed for this study. These tests included laboratory testing and computer programming software which helped the researcher predict the load capacity reduction of RC beam and slab connection with cold joints by considering the angle of inclination, surface location, time of pouring, time of curing, and type of adhesives. The researchers used the three-point loading test to obtain data regarding the structural behavior and response of RC beam and slab connection with cold joints under applied loads. The data gathered from the three-point loading test such as the flexural strength and deflection were used as an input to MATLAB. Similarly, the angle of inclination, time of pouring and curing, surface location, and type of adhesive were also used as input data for the ANN software. With the use of MATLAB, researchers created mathematical models and results that helped interpret the behavior of the structure under cold joints. Lastly, to visualize the performance of an RC beam and slab connection afflicted with cold joint, ANSYS Simulation was utilized. By considering deflection as an input, the researchers could observe how beam and slab connection with cold joint performed through 3D modeling simulations.

2.2Data Collection Method

For the analysis of reinforced concrete connections with cold joints, the three-point loading system, MATLAB, and ANSYS are used as part of a comprehensive data collection procedure.

The parameters of reinforced concrete beams were employed with dimensions of 6 inches × 6 inches × 21 inches and considering 10-millimeter diameter of main bars. A three-point loading arrangement was used in the setup to examine the behavior of the beam. The simulation covered slab dimensions and guaranteed a minimum thickness of 100 millimeters, with an emphasis on a 1-meter strip. The minimum main diameter for the slab reinforcement was 10 millimeters, and the minimum diameter for the temperature reinforcement was 8 millimeters. The slab was also built with a structural cover of 25 millimeters and a minimum concrete cover of 20 millimeters. These criteria, which were derived from the ACI requirements, helped provide a thorough analysis of the behavior of connections in the designated area.

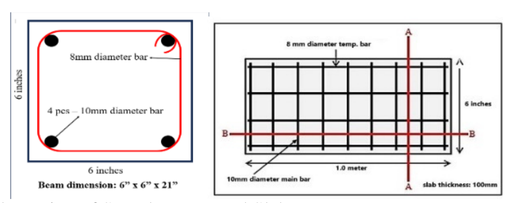

Figure 2. Design of Sample Beam and Slab

The basis of the experimental data was methodically collected through physical testing on 6 inches × 6 inches × 21 inches reinforced concrete beams and considering a 1-meter strip on the slab utilizing a three-point loading system. To ensure cold joints on sample beams and slabs, a 4-hour time interval between pouring was utilized. Also, in accordance with NSCP 2015, the location of cold joints was defined at ¼ of the span of the beam and slab.

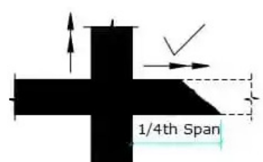

Figure 3. Location of Cold Joints

The structural reaction under various loading scenarios is captured by this process. The following are used to solve thedeflection, flexural stress, bending moment, and flexural modulus in beam and slab:

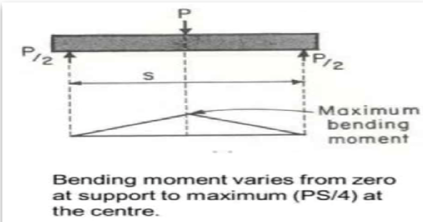

Figure 4. Sample Beam under the Three-Point Loading Test

Deflection

$$\delta = \frac{PS^3}{48EI}$$

Flexural Modulus

$$E = \frac{S^3 m}{4bd^3}$$

Flexural Stress

$$\sigma = \frac{3PS}{2bd^2}$$

Inertia

$$I = \frac{bh^3}{12}$$

Bending Moment

$$M = \frac{PS}{4}$$

MATLAB was used to handle and examine the experimental data. Its powers were applied to feature extraction, data organizing, and cleaning, guaranteeing a sophisticated comprehension of the gathered data. The tool was more accurate at identifying patterns and pertinent aspects from the physical tests because of its expertise with matrix operations and statistical analyses. Concurrently, finite element simulations were performed using ANSYS, which offered a virtual model of the behavior of the connection according to the given dimensions. Slab dimensions were included in this simulation, with a 1-meter strip as the focus, to provide a detailed investigation of the behavior of the connection in a particular area. Finite element analysis, in which ANSYS excelled, enabled a comprehensive virtual testing strategy that took into account intricate structural responses under many loading conditions.

In addition to physical testing, the integrated use of MATLAB and ANSYS improved the precision and dependability of load capacity estimates for reinforced concrete beam and slab connections with cold joints. The combination of ANSYS simulations, MATLAB analysis, and experimental data created a strong technique that enabled an in-depth examination of these relationships. MATLAB and ANSYS were essential tools in this thorough data gathering process because they allowed for the simulation of the behavior of reinforced concrete connections with cold joints and the extraction of valuable information.

Figure 5. Actual Beam and Slab Samples

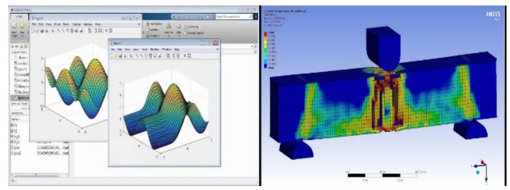

Figure 6. Sample Interface of MATLAB and ANSYS

2.3 Data Analysis

The researchers aimed to examine two types of testing methods for determining the flexural strength of beam and slab connections. Three-point loading was employed as the testing method, which involved applying a load at three distinct points on the object. This loading configuration helped in assessing the structural integrity and deformation characteristics of the materials. The researchers also planned to use MATLAB, a programming software, to predict theaccuracy of the beam and slab testing results, particularly the deflection of the sample beam and slab used in the experiment. By utilizing data analysis and prediction algorithms of MATLAB through applying backpropagation neural network, they intended to assess the reliability and correctness of the testing outcomes, therefore implying a sensitivity analysis among the key factors.

By employing both MATLAB and ANSYS software, the researchers had a comprehensive approach to simulate statistical treatment in their study. The integration of these tools allowed them to simulate the system, generate data, and perform thorough statistical analysis on the simulated data. This resulted in a better understanding of the behavior of the beam-slab connection with the presence of cold joints. Also, it made informed conclusions on how it affected the structural integrity of structures and may have affected their longevity and durability in the long run.

III. RESULTS AND DISCUSSIONS

The Chapter 3 tackled the results gathered from the data collection methods performed by the researchers. In this chapter, the objectives were tried to achieve by observing the behavior of the beam-slab connection with cold joints under different properties: angle of inclination of cold joint, time of pouring and curing, surface position, and type of adhesive. To achieve this, actual testing was conducted in accordance with ASTM C78/C78M, also known as the Three-Point Loading Test. Additionally, a neural network model generated through the Backpropagation Neural Network Algorithm was used to predict the beam-slab connections' load capacity. Finally, to simulate the results in a threedimensional model, ANSYS Static Structural was employed by the researchers.

3.1 Three-Point Loading Test Results for Beam Samples

The data obtained from the three-point loading test conducted on fourteen (14) reinforced concrete beam samples that cured for 7 days, each measuring 155 mm x 155 mm, were summarized in Table 1. This table provided a comprehensive overview of the results obtained from the experimental testing, including key parameters such as load capacities, deflections, and failure modes. Analyzing this data allowed for a detailed understanding of the structural performance of the tested beam samples under various loading conditions.

TABLE 1.
PROPERTIES OF RC SAMPLE BEAMS

Sample No.	Length (mm)	Width (mm)	Thickness (mm)	Main Bar Diameter (mm)	Stirrups Diameter (mm)	Time of Curing (days)	Pouring Interval (hours)	Angle of Inclination (degrees)	Type of Adhesive	Sample Code
1	530	155	155	10	8	7	4	0	N.	C-M1
2	530	155	155	10	8	28	4	0	N	C-M2
3	530	155	155	10	8	7	4	45	N	7-N45
4	530	155	155	10	8	28	4	45	N	28-N45
5	530	155	155	10	8	7	4	45	E	7-E45
6	530	155	155	10	8	28	4	45	E	28-E45
7	530	155	155	10	8	7	4	45	S	7-S45
8	530	155	155	10	8	28	4	45	S	28-S45
9	530	155	155	10	8	7	4	90	N	7-N90
10	530	155	155	10	8	28	4	90	N	28-N90
11	530	155	155	10	8	7	4	90	E	7-E90
12	530	155	155	10	8	28	4	90	E	28-E90
13	530	155	155	10	8	7	4	90	S	7-S90
14	530	155	155	10	8	28	4	90	S	28-S90

Legend: N - No Adhesive E - Epoxy Grout S - Joint Sealant

TABLE 2
LOAD CAPACITY RESULTS FOR RC SAMPLE BEAMS (7 DAYS)

Sample No.	Sample Code	Load (kN)	Stress (MPa)	Flexural Strength (MPa)	Deflection (mm)
1	C-M1	58.72	2.444	12.535	5.3
3	7-N45	44.46	1.851	9.491	5.7
5	7-E45	49.77	2.072	10.625	6.4
7	7-S45	32.67	1.360	6.974	6.1
9	7-N90	35.09	1.461	7.491	4.12
11	7-E90	41.06	1.710	8.765	4.9
13	7-S90	43.11	1.794	9.203	6.6

From the table above, Sample 1 represented the monolithic sample, serving as the control sample for the researchers. Among the other samples, Sample 1 demonstrated the highest flexural strength that the RC sample beam could carry, with a maximum load of 58.720 kN and garnered a flexural strength of 12.535 MPa, obtained from the three-point loading test. In comparison with the other samples, which also cured for 7 days, the obtained results from their maximum load and flexural strength represented a decrease in loading capacity due to the presence of cold joints and the application of various factors to the samples.

On the other hand, among samples employed with cold joints and cured for 7 days, Sample 5 or 7-E45 displayed promising results by obtaining the highest maximum load of 49.77 kN and the highest flexural strength of 10.625 MPa from the actual test. This sample had a cold joint angle of 45 degrees and was infused with an epoxy grout adhesive. Conversely, the sample that obtained the lowest loading capacity was 7-S45 sample. This result highlights the influence of adhesive type on the loading capacity of beams infused with cold joints. In related literature, the researchers provided studies that investigated the effects of various adhesive types on the structural performance of reinforced concrete elements with cold joints.

Additionally, to further analyze the obtained data from the three-point loading test, the table presented below shows the results from the RC sample beams cured for 28 days. The table outlines the different parameters measured for each sample, including flexural strength, maximum load capacity, deflection, and stress. From the previous chapter, it was mentioned that the ASTM C192/C192M-19, Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory, recommended a minimum curing duration of 28 days to ensure that the concrete achieved its maximum strength. [3].

TABLE 3
LOAD CAPACITY RESULTS FOR RC SAMPLE BEAMS (28 DAYS)

Sample No.	Sample Code	Load (kN)	Stress (MPa)	Flexural Strength (MPa)	Deflection (mm)
2	C-M2	69.23	2.882	14.780	5.3
4	28-N45	49.32	2.053	10.529	5.7
6	28-E45	51.20	2.131	10.931	6.4
8	28-S45	46.75	1.946	9.981	6.1
10	28-N90	39.87	1.660	8.512	4.12
12	28-E90	49.03	2.041	10.467	4.9
14	28-S90	45.36	1.888	9.684	6.6

From Table 3, C-M2 was cured for 28 days, allowing the compressive strength of the concrete reach its maximum. The controlled sample obtained a maximum load capacity of 69.230 kN, a stress of 2.882 MPa, a flexural strength of 14.780 MPa, and deflection of 5.3 mm. This sample garnered the highest load capacity among the other samples that cured for 28 days.

On the other hand, the samples with cold joints obtained a relatively low load bearing capacity compared to the monolithic sample. Among these samples, Sample 6, with a sample code of 28-E45, featuring a 45-degree angle of inclination for the cold joint and an epoxy grout adhesive, displayed the highest maximum load of 51.20 kN. This result corresponded with those obtained from samples cured for 7 days.

Additionally, the results indicate that 28-N90 obtained the lowest loading capacity of 39.87 kN. This underscores the impact of adhesive on cold joint formation in the beam sample. Although it differs from the lowest load capacity observed in samples cured for 7 60 61 days, these results aid researchers in gaining a deeper understanding of the effects of adhesives and curing time on RC sample beams.

Research by Tada et al. [4] investigated the impact of cold joint formation angles on the flexural strength of concrete specimens. They found that specimens with a 45-degree angle of inclination for cold joint formation exhibited improved mechanical properties, including higher flexural strength. Additionally, studies by Lee and Kim [5] showed that epoxy grout application on cold joints contributed to enhanced bonding and improved flexural strength of concrete elements.

In Table 4, the load capacity reduction of sample beams with cold joints and cured for 7 days was evident in comparison with the load capacity of the sample beam poured monolithically. The difference in load was calculated, and the reduction in load capacity was interpreted in terms of percentage to maximize the comparison of the sample beams.

From this table, Sample 5 exhibited the lowest percentage reduction in load capacity compared to the controlled sample, C-M1. With a percentage reduction of 15.242%, this sample demonstrated the smallest decrease in strength despite the presence of a cold joint.

TABLE 4
LOAD CAPACITY REDUCTION RESULTS FOR RC SAMPLE BEAMS (7 DAYS)

Sample No.	Sample Code	Load (kN)	Difference in Load (kN)	Percentage Reduction (%)
1	C-M1	58.72		
3	7-N45	44.46	14.26	24.285
5	7-E45	49.77	8.95	15.242
7	7-S45	32.67	26.05	44.363
9	7-N90	35.09	23.63	40.242
11	7-E90	41.06	17.66	30.075
13	7-S90	43.11	15.61	26.584

The table below compared the cold jointed samples that underwent a 28-day curing period to the monolithic sample with the same duration of curing. According to the findings, 28-E45 displayed the least percentage decrease in load capacity compared to the control sample, C-M2. With a reduction percentage of 26.044%, Sample 6 showed the least decline in strength despite having a cold joint.

TABLE 5
LOAD CAPACITY REDUCTION RESULTS FOR RC SAMPLE BEAMS (28 DAYS)

Sample No.	Sample Code	Load (kN)	Difference in Load (kN)	Percentage Reduction (%)
2	C-M2	69.23		
4	28-N45	49.32	19.91	28.759
6	28-E45	51.2	18.03	26.044
8	28-S45	46.75	22.48	32.471
10	28-N90	39.87	29.36	42.409
12	28-E90	49.03	20.20	29.178
14	28-S90	45.36	23.87	34.479

According to Borujerdi et al. [6], the presence of cold joints significantly reduced the load-carrying capacity of the beams compared to monolithic structures. Cold joints created discontinuities in the concrete, leading to stress concentrations and reduced structural integrity, which ultimately resulted in lower load capacities. Also, they observed a decrease in load capacity and increased vulnerability to crack propagation in beams with cold joints. This decrease was attributed to the interruption of the concrete's continuity and the formation of weak planes at the joint interface.

3.2 Three-Point Loading Test Results for Slab Sample

The RC sample slab specifications outlined in Chapter 2 of the research design were consistently utilized from data collection through result simulation. Table 9 illustrated the properties utilized for each sample, providing readers with a reference point throughout the discussion. The meticulous application of these specifications ensured the reliability and validity of the study's findings, reinforcing the credibility of the research outcomes.

TABLE 6
PROPERTIES OF RC SAMPLE SLABS

Sample No.	Length (mm)	Width (mm)	Thickness (mm)	Main Bar Diameter (mm)	Temperature Bar Diameter (mm)	Time of Curing (days)	Pouring Interval (hours)	Angle of Inclination (degrees)	Type of Adhesive	Code Name
1	1000	155	100	10	8	7	4	0	N.	C-M1
2	1000	155	100	10	8	28	4	0	N	C-M2
3	1000	155	100	10	8	7	4	45	N	7-N45
4	1000	155	100	10	8	28	4	45	N	28-N45
5	1000	155	100	10	8	7	4	45	E	7-E45
6	1000	155	100	10	8	28	4	45	E	28-E45
7	1000	155	100	10	8	7	4	45	S	7-S45
8	1000	155	100	10	8	28	4	45	S	28-S45
9	1000	155	100	10	8	7	4	90	N	7-N90
10	1000	155	100	10	8	28	4	90	N	28-N90
11	1000	155	100	10	8	7	4	90	E	7-E90
12	1000	155	100	10	8	28	4	90	E	28-E90
13	1000	155	100	10	8	7	4	90	S	7-S90
14	1000	155	100	10	8	28	4	90	S	28-S90

Legend: N - No Adhesive E - Epoxy Grout S - Joint Sealant

In Table 6, a summary of the experimental data from reinforced concrete slab samples, which were also cured for 7 days and tested using ASTM C78/C78M standards, was presented. The table included parameters such as maximum load capacity, stress, flexural strength, and deflection for each sample.

TABLE 7
LOAD CAPACITY RESULTS FOR RC SAMPLE SLABS (7 DAYS)

Sample No.	Sample Code	Load (kN)	Stress (MPa)	Flexural Strength (MPa)	Deflection (mm)
1	C-M1	20.34	1.312	19.683	1.6
3	7-N45	18.55	1.197	17.951	5.7
5	7-E45	18.59	1.199	17.990	6.4
7	7-S45	12.20	0.787	11.806	6.1
9	7-N90	12.59	0.812	12.183	4.12
11	7-E90	16.53	1.066	15.997	4.9
13	7-S90	12.90	0.832	12.484	6.6

From the table above, C-M1 served as the control variable, poured monolithically, and exhibited the highest flexural strength among the 7-day cured samples, with a maximum load of 20.340 kN and a flexural strength of 19.683 MPa. In comparison with the other samples, which also cured for 7 days, the other samples demonstrated reduced loading capacities and flexural strengths due to factors like cold joints.

Among the samples cured for 7 days, 7-E45 showed promising results with the highest maximum load of 18.590 kN and flexural strength of 17.990 MPa. Notably, Sample 7 had the lowest loading capacity despite a similar cold joint angle, indicating the impact of adhesive type. Furthermore, for a deeper examination of the data gathered from the three-point loading test, the subsequent table illustrates the outcomes from the RC samples cured for 28 days. This table outlines various parameters assessed for each sample, including flexural strength, maximum load capacity, deflection, and stress. As previously noted in the preceding section, ASTM C192/C192M-19 recommends a minimum curing duration of 28 days to ensure optimal strength attainment of concrete.

TABLE 8
LOAD CAPACITY RESULTS FOR RC SAMPLE SLABS (28 DAYS)

Sample No.	Sample Code	Load (kN)	Stress (MPa)	Flexural Strength (MPa)	Deflection (mm)
2	C-M2	25.54	1.648	24.716	4.5
4	28-N45	20.44	1.319	19.781	3.0
6	28-E45	21.76	1.404	21.058	3.3
8	28-S45	15.85	1.023	15.339	2.5
10	28-N90	15.73	1.015	15.223	2.7
12	28-E90	19.77	1.275	19.132	3.5
14	28-S90	14.97	0.966	14.487	3.7

From the data presented in Table 8, Sample 2 underwent a 28-day curing period, enabling the concrete's compressive strength to reach its maximum. The controlled sample exhibited a maximum load capacity of 25.54 kN, a stress of 1.648 MPa, a flexural strength of 24.716 MPa, and a deflection of 4.5 mm. Among the samples cured for 28 days, this sample demonstrated the highest load capacity.

Conversely, samples containing cold joints exhibited relatively lower load-bearing capacities compared to the monolithic sample. Among these, 28-E45 sample, characterized by a 45-degree cold joint inclination and an epoxy grout adhesive, showed the highest maximum load of 21.76 kN. This finding aligns with results obtained from samples cured for 28 days.

TABLE 9
LOAD CAPACITY REDUCTION RESULTS FOR RC SAMPLE SLABS (7 DAYS)

Sample No.	Sample Code	Load (kN)	Difference in Load (kN)	Percentage Reduction (%)
1	C-M1	20.34		
3	7-N45	18.55	1.79	8.8
5	7-E45	18.59	1.75	8.6
7	7-S45	12.20	8.14	40.02
9	7-N90	12.59	7.75	38.102
11	7-E90	16.53	3.81	18.732
13	7-S90	12.90	7.44	36.578

From the provided data, Sample 5 displayed the least percentage reduction in load capacity compared to the control sample, Sample 1 or C-M1. With a reduction percentage of 8.6%, this sample exhibited the smallest decrease in strength despite the existence of a cold joint.

Table 9 emphasized the comparison between sample slabs featuring 45-degree and 90-degree cold joints and the monolithic samples, focusing on the influence of adhesive type on each sample. Analysis of the charts revealed a decrease in loading capacity for sample slabs with cold joints. Despite the sample with epoxy grout and a 45 degree cold joint achieving the highest maximum load, it still fell short of the maximum load attained by the control sample. Thus, the sample with a 45-degree cold joint and epoxy grout exhibited the highest maximum load among samples with similar properties; however, it still experienced a decrease compared to the monolithic sample, by a percentage of 8.6%.

TABLE 10
LOAD CAPACITY REDUCTION RESULTS FOR RC SAMPLE SLABS (28 DAYS)

Sample No.	Sample Code	Load (kN)	Difference in Load (kN)	Percentage Reduction (%)
2	C-M2	25.54		
4	28-N45	20.44	5.1	19.969
6	28-E45	21.76	3.78	14.8
8	28-S45	15.85	9.69	37.94
10	28-N90	15.73	9.81	38.41
12	28-E90	19.77	5.77	22.592
14	28-S90	14.97	10.57	41.386

The presented table compares the cold-jointed samples cured for 28 days with the monolithic sample having the same curing duration. According to the analysis, Sample 6 exhibited a percentage increase in load capacity compared to the control sample, C-M2. Demonstrating a reduction percentage of

14.8%, Sample 6 with a sample code of 28-E45 indicated the smallest decline in strength despite the presence of a cold joint.

The analysis unveiled a noticeable average decrease of 27.16% in load capacity among samples with cold joints when compared to their monolithic counterparts. These results underscored a significant reduction in the load capacity of the sample slabs when cold joints were present.

Experimental studies conducted by Chen et al. [7] analyzed the mechanical properties of concrete slabs with and without cold joints. They discovered that slabs with cold joints exhibited a decreased load capacity, indicating that the presence of these joints negatively affected structural integrity. Furthermore, they observed that the duration of curing influenced the strength of cold joints, with shorter curing periods resulting in weaker joints and consequently, a further decrease in load capacity. This highlighted the importance of proper curing procedures in ensuring the structural robustness of concrete elements.

3.3 Data Prediction using Backpropagation Neural Network Algorithm

Utilizing the backpropagation neural network algorithm, researchers analyzed input data derived from three-point loading tests. Their aim was to forecast the maximum loading capacity of sample beam and slab connections possessing different properties from the samples that underwent actual testing.

The outcomes, as detailed in table 11, showcased the predicted maximum load for sample beams featuring an existing cold joint inclined at angles of 30 degrees, 60 degrees, and 120 degrees. This approach enabled the researchers to anticipate the structural performance of such connections under varying conditions, providing valuable insights for engineering and construction applications. These predictions served as a practical guide for optimizing joint configurations and reinforcing design strategies to enhance the overall stability and load-bearing capacity of concrete structures in real-world scenarios.

TABLE 11
LOAD PREDICTION OF RC BEAMS WITH COLD JOINTS (30^O, 60^O, AND 120^O)

Sample No.	Angle of Inclination of Cold Joint	Time of Curing	Type of Adhesive	Predicted Maximum Load (kN)	Validation Error (%)	Sample Code
1	30	7	N	47.320	1.761	7-N30
2	30	28	N	50.120	0.448	28-N30
3	30	7	E	51.290	0.025	7-E30
4	30	28	E	53.190	0.000	28-E30
5	30	7	S	40.760	0.053	7-S30
6	30	28	S	46.700	0.000	28-S30
7	60	7	N	36.140	0.004	7-N60
8	60	28	N	43.740	1.020	28-N60
9	60	7	E	41.790	3.610	7-E60
10	60	28	E	50.110	0.740	28-E60
11	60	7	S	39.210	0.000	7-S60
12	60	28	S	49.180	0.001	28-S60
13	120	7	N	42.130	0.004	7-N120
14	120	28	N	45.850	1.020	28-N120
15	120	7	E	44.110	1.410	7-E120
16	120	28	E	46.260	0.267	28-E120
17	120	7	S	38.960	0.000	7-S120
18	120	28	S	40.550	0.001	28-S120

Legend: N - No Adhesive E - Epoxy Grout S - Joint Sealant

From the line graph below, a comparison among RC sample beams cured for 7 days was presented. Despite differences between them, the sample with a 30-degree inclined cold joint infused with epoxy grout obtained the highest maximum load-bearing capacity, with a predicted maximum load of 51.29 kN. Similar results were obtained among the samples tested through the three-point loading test.

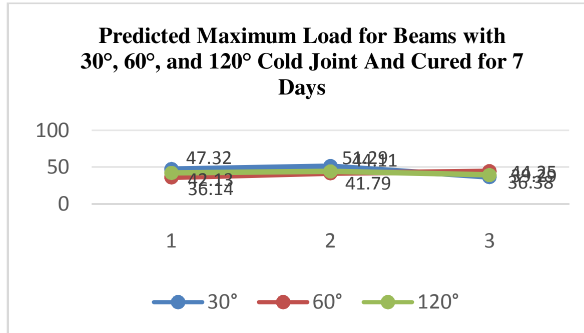

Figure 7. Comparison of Predicted Loads for RC Sample Beams (7 Days)

In other words, the researchers observed that RC sample beams with cold joints inclined at smaller degrees would obtain the highest maximum loading capacity, as long as the cold joint was sealed with epoxy grout. This result clearly demonstrates the effectiveness of epoxy grout in mitigating the negative effects of cold joints on the structural integrity of the beam member.

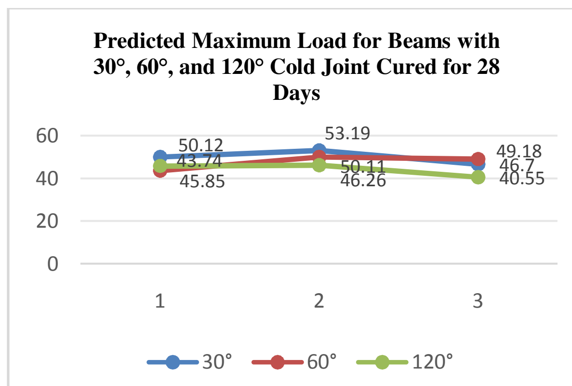

Figure 8. Comparison of Predicted Loads for RC Sample Beams (28 Days)

On the other hand, the line graph provided above displayed a comparison of samples that underwent a 28-day curing period. Despite the differences in the factors applied, the sample featuring a 30-degree inclined cold joint treated with epoxy grout still achieved the highest maximum load-bearing capacity, reaching a predicted maximum load of 53.19 kN. Comparable outcomes were also observed among the samples subjected to the three-point loading test. With these results, similar conclusions were obtained from the researchers, stating that RC sample beams with cold joints inclined at lesser angles would achieve the highest maximum loading capacity, provided that the cold joint was sealed with epoxy grout. Nevertheless, even though it attained the greatest maximum load among the samples with cold joints, the result still fell short of the load capacity of the monolithic sample. This observation underscored the distinction between a monolithic sample and one with a delayed pouring process, a method commonly employed in construction projects, specifically among large-scaled projects.

In summary, by utilizing the backpropagation neural network (BPNN) algorithm, the researchers were able to theoretically determine the maximum load-bearing capacity of RC sample beams with cold joints at various angles of inclination. This approach allowed them to predict the structural behavior of the beams without the need for extensive physical testing. By comparing the predicted maximum load capacities with the actual test results, the researchers gained valuable insights into how different factors, such as the angle of inclination of the cold joints, affected the structural integrity of the beams. Overall, the application of the BPNN algorithm provided a theoretical framework for understanding the behavior of RC sample beams with cold joints, complementing the experimental findings obtained through actual testing.

Furthermore, researchers utilized the backpropagation neural network algorithm to examine input data obtained from three-point loading tests. Their objective was to predict the maximum loading capacity of sample beam and slab connections with properties differing from those of the samples used in actual testing. The results, outlined in Table 16, revealed the anticipated maximum load for sample slabs with pre-existing cold joints inclined at angles of 30 degrees, 60 degrees, and 120 degrees.

TABLE 1
LOAD PREDICTION OF RC SLABS WITH COLD JOINTS (30^O, 60^O, AND 120^O)

Sample No.	Angle of Inclination of Cold Joint	Time of Curing	Type of Adhesive	Predicted Maximum Load (kN)	Validation Error (%)	Sample Code
1	30	7	N.A.	16.234	0.069	7-N30
2	30	28	N.A.	19.478	0.026	28-N30
3	30	7	E.G.	23.201	0.320	7-E30
4	30	28	E.G.	28.250	0.098	28-E30
5	30	7	J.S.	18.932	0.081	7-S30
6	30	28	J.S.	19.416	0.047	28-S30
7	60	7	N.A.	16.584	0.000	7-N60
8	60	28	N.A.	19.995	0.094	28-N60
9	60	7	E.G.	21.038	0.000	7-E60
10	60	28	E.G.	21.544	0.019	28-E60
11	60	7	J.S.	20.475	0.041	7-S60
12	60	28	J.S.	20.695	0.025	28-S60
13	120	7	N.A.	12.014	0.089	7-N120
14	120	28	N.A.	14.299	0.036	28-N120
15	120	7	E.G.	14.727	0.071	7-E120
16	120	28	E.G.	16.681	0.140	28-E120
17	120	7	J.S.	12.036	0.082	7-S120
18	120	28	J.S	15.683	0.044	28-S120

Legend: N – No Adhesive E – Epoxy Grout S – Joint Sealant

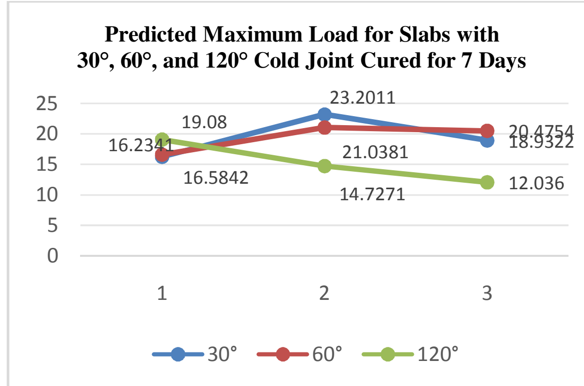

Figure 9. Comparison of Predicted Loads for RC Sample Slabs (7 Days)

From the line graph above, a comparison among samples cured for 7 days is presented. Despite variations among the samples, the one with a 30-degree inclined cold joint treated with epoxy grout stood out by achieving the highest maximum load-bearing capacity of 23.201 kN, as predicted. This finding was consistent with results obtained from other testing methods, such as the three-point loading test, and predicted load capacities from sample beams. These results suggest that the 30-degree inclined cold joint, when treated with epoxy grout, significantly enhanced the load-bearing capacity of RC sample slabs, providing valuable insights for construction and engineering applications.

Additionally, these findings led to a similar conclusion as stated by the researchers: RC sample beams with cold joints inclined at smaller angles would achieve the highest maximum loading capacity, given that the cold joint was sealed with epoxy grout. However, despite achieving the highest maximum load among the samples with cold joints, the result still did not match the load capacity of the monolithic sample.

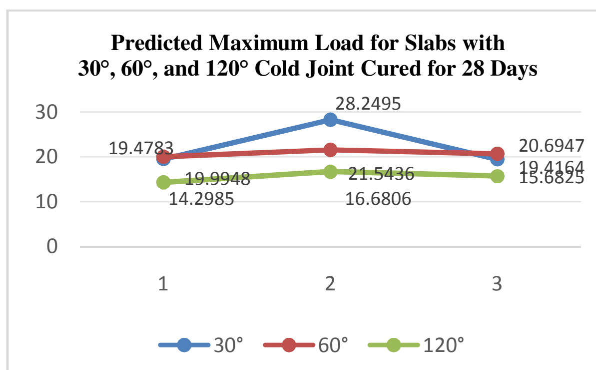

Figure 10. Comparison of Predicted Loads for RC Sample Slabs (28 Days)

The line graph above illustrated the comparison of maximum loads obtained through the analysis and application of the backpropagation neural network learning. From the graph, it was evident that the sample cured for 28 days with a 30-degree angle of inclination for cold joints still attained the highest maximum load force that the sample slab could withstand. This finding aligned with the previously mentioned results. Furthermore, it remained clear that there was a distinct decrease in the load-bearing capacity of a sample slab when infused with cold joints compared to the results obtained from monolithic samples. Additionally, with a mean variation error of 0.077%, the researchers' generated backpropagation neural network model worked promising with the garnered results. This suggested that utilizing backpropagation network analysis could offer an efficient alternative to traditional methods, such as destructive testing, thus saving valuable time and resources in structural analysis.

3.4 ANSYS Simulation of Predicted Data of Sample Beams and Slabs from BPNN

The integration of ANSYS Simulation facilitated a thorough analysis of sample beams' performance under various loading conditions, offering insights into their structural behavior. Standardized to dimensions of 155 mm x 155 mm x 530 mm, with 100 mm spacing for main bars and stirrups, the beams ensured consistency across analyses. Using MATLAB, the researcher generated loads applied to the sample beams, allowing precise control and customization of loading conditions for accurate simulations. These loads simulated real-world scenarios, assessing the beams' response to different external forces and stress distributions. Considering the crucial role of concrete's compressive strength, a compressive strength of 1950 psi for 7-day cured concrete and 3000 psi for 28-day cured concrete was adopted, aligning with standard practices outlined in Section 19.2.1.3 of ACI 318-19. This adherence ensured consistency and reliability in the analysis. Acknowledging that 7-day cured concrete typically has about 65% of the strength of 28-day cured concrete was essential, highlighting the importance of curing duration in assessing structural performance. By adhering to established guidelines and industry standards, the ANSYS Simulation analysis rigorously evaluated the sample beams' structural integrity and load carrying capabilities, providing valuable insights for engineers and researchers to guide design decisions and optimize reinforced concrete structures' performance in practical applications.

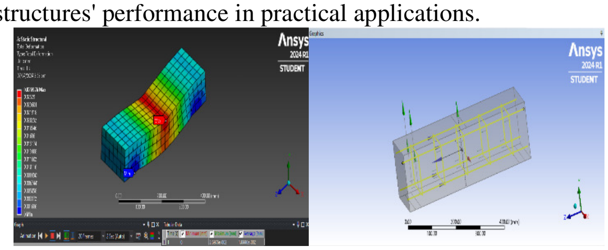

Figure 11. Simulated RC Sample Beam and Slab

Through the integration of ANSYS Static Structural analysis, the following results were generated for each sample beam and slab connection. The simulation visualized the actual deformation of the samples with the integration of similar properties from the actual sample beams and slabs. One of the key benefits of using ANSYS Static Structural analysis was its ability to visualize the deformation of structures under different loading scenarios. By applying loads to the simulated model and solving the equations governing structural behavior, engineers could observe how the beams and slabs deformed in response to these loads. This visualization provided valuable insights into potential areas of stress concentration, deformation patterns, and overall structural performance.

TABLE 13.
ANSYS SIMULATED RC SAMPLE BEAM RESULTS

Sample Number	Sample Code	Total Deformation (mm)	Maximum Shear Stress (MPa)	Normal Stress (MPa)	Shear Stress (MPa)
1	7-N30	0.068	12.452	13.085	2.362
2	28-N30	0.072	13.189	13.859	2.502
3	7-E30	0.074	13.497	14.183	2.561
4	28-E30	0.076	13.997	14.708	2.656
5	7-S30	0.059	10.726	11.271	2.035
6	28-S30	0.067	12.289	12.913	2.332
7	7-N60	0.052	9.510	9.993	1.804
8	28-N60	0.063	11.51	12.095	2.184
9	7-E60	0.060	10.997	11.556	2.087
10	28-E60	0.072	13.186	13.856	2.502
11	7-S60	0.056	10.318	10.842	1.958
12	28-S60	0.071	12.941	13.599	2.456
13	7-N120	0.061	11.086	11.65	2.104
14	28-N120	0.066	12.065	12.678	2.289
15	7-E120	0.063	11.607	12.197	2.202
16	28-E120	0.066	12.173	12.792	2.310
17	7-S120	0.056	10.252	10.773	1.945
18	28-S120	0.058	10.67	11.213	2.025

In summary, all of the samples with the highest total deformation, maximum shear stress, normal stress, and shear stress, whether angled at 30 degrees, 60 degrees, or 120 degrees for cold joints, were sealed with epoxy grout. The results showed that sample 4 had been the strongest sample, as it could resist the highest load among all other samples before reaching its total deformation, while beam sample 7 had been found to be the weakest sample. Additionally, ANSYS simulation results had confirmed that cold joints with a lower inclination angle had exhibited the most significant maximum values, while a greater angle of inclination had shown the lowest maximum values regarding total deformation, maximum shear stress, normal stress, shear stress, and load-bearing capacity.

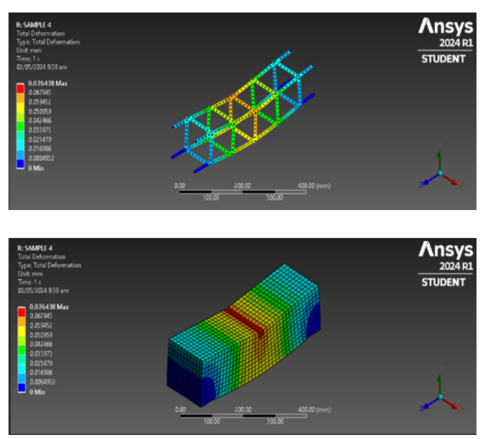

Figure 12. Sample Beam Number 4 (28-E30)

The ANSYS simulation results provided insights into the structural behavior of eighteen reinforced concrete one-way slab samples, all measuring 155 mm x 1000 mm. Interestingly, to evaluate the impact of joint presence on structural performance, these samples underwent data prediction employing the Backpropagation Neural Network (BPNN) with and without cold joints. There was a noticeable difference in the samples' compressive strength values: samples 2, 4, 6, 8, 10, 12, 14, 16, and 18 had greater compressive strength values of 3000 PSI, whereas samples 1, 3, 5, 7, 9, 11, 13, 15, and 17 had compressive strength values of 1950 PSI. This variation in compressive strength among the samples served as a foundation for assessing how their structures reacted to different loads and stresses. Additionally, the reinforcing bars used in these eighteen slab samples had a diameter of 10mm and 8mm for main bars and temperature bars, respectively

TABLE 14
ANSYS SIMULATED RC SAMPLE SLAB RESULTS

Sample Number	Sample Code	Total Deformation (mm)	Maximum Shear Stress (MPa)	Normal Stress (MPa)	Shear Stress (MPa)
1	7-N30	0.029	2.795	4.748	0.644
2	28-N30	0.035	3.353	5.696	0.733
3	7-E30	0.042	3.994	6.785	0.921
4	28-E30	0.051	4.863	8.261	1.121
5	7-S30	0.034	3.259	5.537	0.751
6	28-S30	0.035	3.342	5.678	0.771
7	7-N60	0.030	2.858	4.850	0.658
8	28-N60	0.036	3.442	5.847	0.794
9	7-E60	0.038	3.622	6.153	0.835
10	28-E60	0.039	3.709	6.300	0.855
11	7-S60	0.037	3.525	5.988	0.813
12	28-S60	0.037	3.562	6.052	0.821
13	7-N120	0.022	2.068	3.513	0.477
14	28-N120	0.026	2.461	4.182	0.567
15	7-E120	0.027	2.535	4.307	0.584
16	28-E120	0.030	2.871	4.878	0.662
17	7-S120	0.022	2.072	3.520	0.478
18	28-S120	0.028	2.700	4.586	0.622

Legend: For Sample Codes, Curing Days-Type of Adhesive-Angle of Inclination

In summary, among all the slab samples that had 28 days' time of curing and cold joints inclined at angles of 30 degrees, 60 degrees, and 120 degrees, it became clear and evident after thorough data analysis using the ANSYS simulation that sample number 4, which had an adhesive of epoxy grout, 28 days' time of curing, 30 degrees angle of inclination, and a load force of 28.250 kN, had the maximum value of 0.051 mm, 4.863 MPa, 8.261 MPa, and 1.121 MPa for total deformation, maximum shear stress, normal stress, and shear stress respectively. Sample number 14, on the other hand, which had a 120-degree angle of inclination, showed opposing data patterns. Here, the lowest values of total deformation, maximum shear stress, normal stress, and shear stress were found, totaling 0.026 mm, 2.461 MPa, 4.182 MPa, and 0.568 MPa, respectively. As a result, when compared to the other slab samples that had 28 days' time of curing, sample number 14 exhibited the lowest load force applied, measured at 14.299 kN.

Additionally, ANSYS simulation clearly demonstrated that cold joints with less inclination exhibited the highest maximum values for load-carrying capacity, total deformation, maximum shear stress,normal stress, and shear stress. Conversely, a higher angle of inclination resulted in the lowest maximum values for total deformation, maximum shear stress, normal stress, and shear stress as well as load-bearing capacity.

The idea that there was a direct correlation between the outcomes of the ANSYS and MATLAB simulations was reinforced by the consistent alignment of load forces and material characteristics as well as the noted patterns of sample behavior. This connection provided confidence in the correctness and dependability of the analytical predictions produced by both platforms, as well as highlighted the durability of the computational models used. Furthermore, by aligning the results from both modeling, researchers and engineers could use the outputs to validate and double-check the findings and improve the understanding of the structural behavior that was studied.

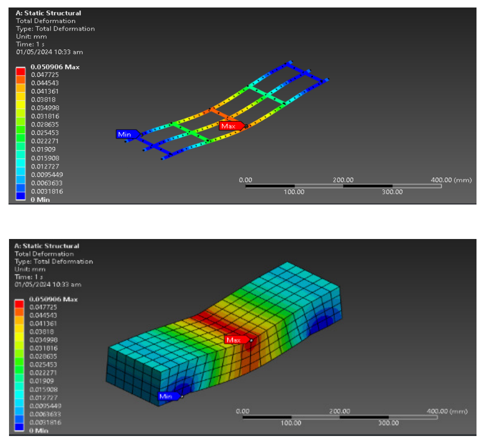

Figure 13. Sample Slab Number 4 (28-E30)

IV. CONCLUSION

The comprehensive analysis of reinforced concrete (RC) beam samples subjected to varying curing durations and angles of inclination for cold joints provided valuable insights into their structural performance under different loading conditions. Through meticulous experimental testing and simulation, significant patterns and trends were observed, shedding light on the influence of various factors such as cold joint formation, adhesive type, and curing time on load-bearing capacity.

Furthermore, the comparison between samples cured for 7 days and those cured for 28 days underscored the impact of curing duration on load-bearing capacity. While prolonged curing enhanced the strength of monolithic samples, those with cold joints still displayed decreased capacities compared to the control sample. The analysis also highlighted the role of adhesive type in mitigating the effects of cold joints, with epoxy grout demonstrating better performance compared to joint sealant. Additionally, the angle of inclination for cold joints played a significant role, with samples featuring a 45-degree angle exhibiting higher load capacities compared to those with a 90 degree angle.

Therefore, the findings emphasize the importance of carefully considering factors such as curing duration, cold joint formation, and adhesive type in structural design and construction practices. By understanding the nuanced interplay of these variables, engineers can optimize the performance and durability of concrete structures, ultimately enhancing their reliability and safety in real-world applications.

For the conducted three-point loading test for RC sample slabs, the thorough examination of reinforced concrete (RC) slab samples, subjected to varying curing durations and angles of inclination for cold joints, provided valuable insights into their structural performance under diverse loading conditions. Throughout the research process, consistent utilization of RC sample slab specifications outlined in Chapter 2 ensured the reliability and validity of the study's findings.

The analysis further underscored the role of adhesive type in mitigating the effects of cold joints, with epoxy grout demonstrating superior performance. Additionally, the angle of inclination for cold joints significantly influenced load capacities, with samples featuring a 45-degree angle exhibiting higher strengths. Findings from related literature studies and empirical data complemented the research outcomes, emphasizing the negative impact of cold joints on structural integrity. Notably, the comparison of cold-jointed samples cured for 28 days with monolithic counterparts revealed a significant reduction in load capacity, further highlighting the importance of adhesive presence and curing duration in maintaining structural integrity.

In other words, the study elucidated the complex interplay of factors influencing the load-bearing capacity of RC slabs, providing valuable insights for structural design and construction practices. By understanding the nuanced effects of cold joints, adhesive types, and curing durations, engineers can optimize the performance and safety of concrete structures in real-world applications, ensuring enhanced reliability and durability.

Overall, the findings demonstrated the effectiveness of backpropagation neural networks in accurately predicting load-deflection behavior in reinforced concrete structures. Consistent with prior research, these results contributed valuable insights into the predictive capabilities of neural networks in structural engineering applications, paving the way for further advancements in computational modeling and analysis techniques.

Utilizing the backpropagation neural network algorithm, researchers analyzed input data derived from three-point loading tests to forecast the maximum loading capacity of sample beam and slab connections with different properties from those of the tested samples. The outcomes, as detailed in Table 16, showcased the predicted maximum load for sample beams featuring cold joints inclined at angles of 30 degrees, 60 degrees, and 120 degrees. This approach provided valuable insights for engineering and construction applications, guiding the optimization of joint configurations and design strategies to enhance the stability and load-bearing capacity of concrete structures.

In utilizing the finite element analysis method using ANSYS, the simulation of data for samples angled at 30 degrees for cold joints revealed notable variations in structural performance among the beam samples. Samples 7-E30 and 28-E30 exhibited the highest total deformation, indicating their ability to withstand heavy loads before reaching their deformation limits. Sample 4, cured for 28 days and sealed with epoxy grout, emerged as the strongest sample, displaying the highest resistance to deformation. Conversely, sample 5 or 7-S30 was identified as the weakest, showcasing the lowest total deformation among the samples at 30 degrees.

Similarly, among samples angled at 60 degrees, 7-E60 displayed the highest total deformation, suggesting its susceptibility to deformation under the given conditions. Consequently, 28-E60 exhibited the highest deformationamong samples at 60 degrees. Notably, samples 7 (7-N60) and 8 (28-N60) were identified as the weakest among both 7 day and 28-day cured samples, indicating their lower resistance to applied loads. The investigation extended to samples with a 120-degree angle of inclination for cold joints, revealing samples 15 (7-E120) and 16 (28-E120) as displaying the highest total deformation and stress magnitudes. These samples exhibited superior mechanical properties, with notable deformation characteristics under applied loads. In contrast, 7 S120 and 28-S120, despite their alignment at a 120-degree inclination, demonstrated inferior performance metrics, suggesting a weaker response to external forces.

The consistency between the ANSYS and MATLAB simulations reaffirmed the accuracy and reliability of the analytical predictions, bolstering confidence in computational models. By aligning results from both platforms, researchers and engineers could validate findings and gain deeper insights into structural behavior, thereby advancing material engineering and construction practices. These findings provided a robust foundation for optimizing design strategies and enhancing the reliability and durability of reinforced concrete structures in real-world applications.

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