

INSTANTANEOUS LOAD-DEFLECTION BEHAVIOUR OF REINFORCED CONCRETE BEAMS

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Abstract

Beam deflection under load and concrete cracking is a ubiquitous phenomenon, present in all types of concrete structures. This research work represents a comparative analysis of experimental and theoretical deflections of simply supported beams with different proportions of mild steel as reinforcement and also different curing conditions i.e. Painting, Air and Water curing. Theoretical deflections were measured using AS 3600-2018, ACI 318-14 and Eurocode 2:2004. To differentiate among these codes Shrinkage was kept variable by different curing conditions. Crack width was measured by image processing using ImageJ software and compared with theoretical results using Eurocode 2:2004 and ACI 224.1R-07. Processing of RGB images with sufficient information will provide the parameters of cracks. RGB images were converted into Gray scale proceed by a filtering and thresholding. Crack parameters were automatically determined by Ridge Detection plugin. Deflections of simply supported beams from experimental and calculation results using AS 3600-2018, Eurocode 2:2004 and ACI 318-14 are very close. Image processing is a very effective technique in the study of crack in concrete and for automatic detection “Ridge Detection” plugin is very helpful.

Keywords: Beam Deflection, Shrinkage, Image Processing, Surface Crack, Ridge Detection

Introduction

Beam deflection refers to the state in which a beam deviates from its initial shape as a result of a force, load, or weight (Charles Head Norris, 2017). Deflection in engineering refers to how much a structural member is shifted by a load (Charles Head Norris, 2017). It could make reference to a distance or an angle. Deflection, also known as displacement, can result from the structure's own weight or from externally applied loads.

Even though a beam has the strength to safely withstand bending moments and shear forces, it may nonetheless be unsuitable because of excessive deflection under the projected safe load. Excessive deflection can split plaster ceilings and walls, which not only looks bad and gives the impression of unreliability but also poses a durability risk.

Additionally, the structure must endure regular service loads without deforming, breaking, or severe

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vibration. Strength and serviceability are thus the two (02) main goals of structural design. The stability of a structure, its resistance to tipping over or sliding, the absence of corrosion in the reinforcement, the resistance of the concrete to abrasion and spalling, and the stability of the structure over time must all be met (Charles Head Norris, 2017).

The designer must ascertain the maximum crack that may be permitted in a concrete wall or floor, as well as the maximum acceptable deflection for a chosen beam or slab. There is a greater chance of excessive deflections in some buildings, such as bridges, which must be discovered and managed.

The scientific and technical communities have given a lot of attention to deflection measurement and crack identification in concrete structures. If left unchecked for a long time, the existence of significant deflection and cracks in a structure will result in system failure, loss of life, and depletion of resources.

Concrete cracks may be an indication of support condition changes, reinforcement corrosion, or spall formation. Therefore, keeping an eye on cracks as concrete structures age has proven an effective method of determining their level of safety and developing plans for future, suitable restoration. The earliest and most reliable approach to identify concrete fractures is human visual inspection.

However, manual examination takes a lot of time, costs money, and could be dangerous for people. As a result, unmanned inspection techniques have become more prevalent during the past ten years, enabling more effective examination. A camera is used to capture RGB images (color images in the Red, Green, and Blue color spaces) at a particular location. To track the crack formations, each image that is collected needs to be assessed. Instead of hiring a person to assess them, this function might be completed by applying image processing techniques to automatically locate and report cracks. Additionally, analyzing RGB photographs with enough details, such as the distance from the camera to the surface for each shot, can reveal the size of the cracks (length and width) (Darwin, 1986).

It has been suggested to use an enhanced image filtering method that can identify the primary cracks in the image, remove any remaining noise, and then discover unclear cracks near the local areas. This method has a high reliance on the image filter, but it can ensure the accuracy of crack width detection.

Real cracks from laboratory trials must be used to validate image-based analysis for crack identification and digital crack measurements before it can be used in real-world applications. By comparing the manual crack measurements from

RCC beam testing to the image analysis-derived crack width measurements, this study aims to show how this new technology can be used in reinforced concrete trials.

Objectives of this study:

To measure deflections and cracks of simply-supported beams experimentally.

To calculate deflections and cracks of simply supported beams using codes.

To compare deflections and cracks of simply supported beams between experimental and calculation results.

Materials and Methods

Materials

In this study Coarse Aggregate, Fine Aggregate, Cement, Reinforcing Bar were used.

Materials property

Coarse Aggregate

Black stone chips were used as coarse aggregate. Specific gravity, absorption, aggregate size and unit weight of black stone chips were found 2.70, 1.2%, 25mm and 1580 kg/m³ respectively.

Fine Aggregate

Coarse sand (Sylhet sand) was used as fine aggregate. Specific gravity, absorption, unit weight and fineness modulus of coarse sand were found 2.65, 3.15%, 1678 kg/m³ and 2.91 respectively.

Binder

Portland composite cement was used as binder.

Reinforcing Bar

500W deformed mild steel reinforcement bars of 12mm and 16mm diameter were used.

Sample preparation

Beams

Six (06) no of reinforcing beams having dimension of 72" × 6" × 8" (L×W×H) were prepared with various proportions of 12mm and 16mm diameter mild steel bars. The bottom clear cover was 1.5" and side clear cover was 1.0" in all directions in all the beams. The average slump value was 85mm and w/c ratio was 0.54. The concrete mix design ratio was 1:1.5:3 (Cement: FA: CA) and the target strength was 20MPa.

All the beams were in water curing for 14 days and then two (02) beams were painted using Acrylic Plastic Emulsion paint for moisture and shrinkage control and the rest four (04) beams were in air curing for 30 days before the tests. Curing and

reinforcing types of beam samples are shown in Table 1, longitudinal and cross section of beams are shown in Figure 1 and Figure 2 and preparation of beam samples is shown in Figure 3.

Table 1. Shows curing and reinforcing types of beam samples

Sample No	Curing Type	Reinforcement
BS-1	14 days water + 30 days painting	2nos 16mm diameter bar
BS-2	14 days water + 30 days painting	3nos 12mm diameter bar
BS-3	14 days water + 30 days air	2nos 16mm diameter bar
BS-4	14 days water + 30 days air	3nos 12mm diameter bar
BS-5	14 days water + 30 days air	2nos 12mm diameter bar
BS-6	14 days water + 30 days air	3nos 16mm diameter bar

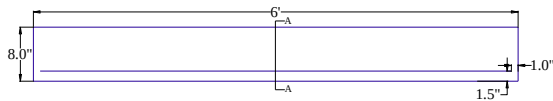
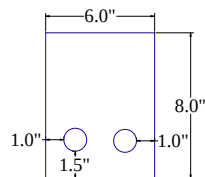
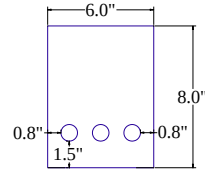


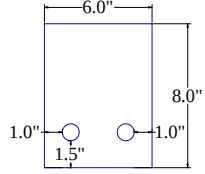
Figure 1. Shows longitudinal section of beams



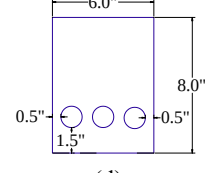
(a)



(b)



(c)



(d)

Figure 2. Shows Cross Section(A-A) of beam samples (a) BS-1 and BS-3, (b) BS-2 and BS-4, (c) BS-5 and (d) BS-6



Figure 3. Shows preparation of beam samples

Cylinders

Total sixteen (16) no of cylinders having dimension of 4"×8" were prepared as the representative of each type of beam. All the cylinders were in water curing for 14days and then three (03) cylinders were painted using Acrylic Plastic Emulsion Paint for moisture and shrinkage control and three (03) cylinders were in air curing and the rest ten (10) cylinders were in water curing for different periods. Curing types of cylinder samples are shown in Table 2 and preparation of cylinder samples is shown in Figure 4.

Table 2. Shows curing types of cylinder samples

Set No	Curing Type
Set-1	14 days water curing
Set-2	28 days water curing
Set-3	44 days water curing
Set-4	14 days water + 30 days paint
Set-5	14 days water + 30 days air curing

Each set carried three (03) no of cylinders except Set-1, which carried four (04) cylinders.

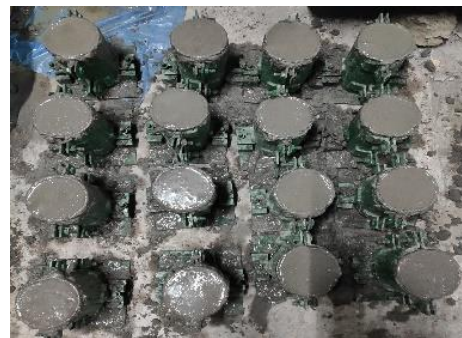


Figure 4. Shows preparation of cylinder samples

Shrinkage Prisms

Total six (06) no of Shrinkage prisms having dimension of 285mm×75mm×75mm were prepared as the representative of each type of beam. The reference bar was 297mm long, so the gauge studs of prisms were 6mm extended in both upper and lower sides. All the Shrinkage prisms were in water curing for 14days and then two (02) Shrinkage prisms were painted using Acrylic Plastic Emulsion paint for moisture and shrinkage control and two (02) Shrinkage prisms were in air curing and the rest two (02) Shrinkage prisms were in water curing. Curing types of shrinkage prisms are shown in Table 3 and preparation of shrinkage prisms is shown in Figure 5.

Table 3. Shows curing types of shrinkage prisms

Set No	Curing Type
Set-1	14 days water + 30 days paint
Set-2	14 days water + 30 days air curing
Set-3	44 days water curing

Each set carried two (02) no of shrinkage prisms.



Figure 5. Shows preparation of shrinkage prisms

Experimental Procedure

Beams

The prepared reinforced beams were set for loading with two (02) supports at the edge of the beams so that it acts as a simply supported beam. Load was applied at the middle point of the beams. Dial gauge was set for deflection measurement at the middle point of beams. Load was gradually applied by a Hydraulic jack and deflection readings were taken. At the same time, images were also taken at load intervals of 1.1kips for crack measurement through image processing. CANON EOS70D camera was used to take images. The camera was set at a specified point to maintain a fixed focal length. A hand handled Microscope was used to take picture and verify with the result of

processed images. Experimental setup for beam load test is shown in Figure 6.



Figure 6. Shows experimental setup for beam load test

Cylinders

Concrete's compressive and tensile strengths were evaluated using cylinder tests. Utilizing a compression strength machine, compression force was applied to the specimen, and failure load was measured. This equation was used to calculate compressive strength.

$$C = P/A \text{ (ASTM C39, 2018)}$$

Where,

C= Compressive strength;

P= Failure load;

A= Contact area.

Compressive strength test was performed according to (ASTM C39, 2018) Experimental setup for compressive strength test is shown in Figure 7.



Figure 7. Shows experimental setup for compressive strength test

Tensile strength of concrete was determined by using following equation (ACI Committee, 2014)

$$f_{ct} = 0.62\sqrt{f'_c}$$

Where,

f_{ct} =Tensile strength of concrete;

f_c' =Compressive strength of concrete.

Shrinkage Prisms

The comparator indication of the length of the reference bar and shrinkage prism were read and recorded. Readings were recorded by rotating the bar clockwise each time and average of two values was taken as reading (C490M-17, 2017). The upper and lower side of prisms was maintained properly by putting mark on the prisms. The readings were recorded daily from day-16 to day-44 after 14days curing of the samples under water. Experimental setup for shrinkage measurement is shown in Figure 8.



Figure 8. Shows experimental setup for shrinkage measurement

Image processing

Image analysis is the technique of extracting useful information from digital photos taken with a camera using image processing. It involves just two simple steps. Image processing is the first step, when images are prepared in stages for subsequent analysis. This includes converting an RGB image to a grayscale image, which is then thresholded to produce a binary (black and white) image. The second stage is analyzing the image that has been processed in step 1 in order to determine the parameters that define the crack patterns, such as the total area of cracks, the total length of cracks, and the average width of cracks (M. Lakshmikantha, 2009).

“Ridge Detection” plugin in ImageJ is helpful for automatic crack length, width, area calculation.

Preparation of the raw images

The RGB (Red, Green, and Blue) image captured by the camera is off-center. Any area can be cropped using the crop option in the ImageJ software. The central portion of the specimen is chosen, and the outer portion is cropped to create a centered RGB image with a white background.

Then, by selecting the option Image-type-8 bit in the ImageJ window, this image is changed to an 8-bit grayscale image. The only colors present in a grayscale image are various degrees of grey. Each pixel in a full color image needs to be specified using three intensities. When the intensity of the red, green, and blue colors in an RGB color space is equal, that color is considered to be grey. Consequently, each pixel just needs to have a single intensity specified.

Grey-Scale Processing

The results will be impacted if there is any illumination on the specimen surface in the camera photos. Grey scale processing was done to enhance the features of interest and rectify it. It takes two simple processes to complete: (a) Remove smooth continuous backgrounds by subtracting the background. (b) An unsharpened mask that improves and sharpens the edges of the image by removing a blurry version of it.

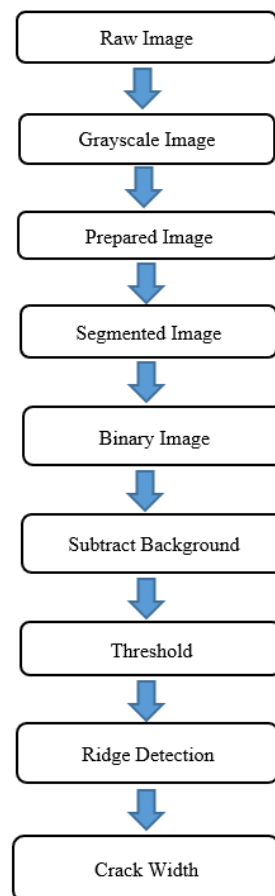


Figure 9. Shows flow diagram of image processing

Image Segmentation

To separate the crack, image segmentation is used. It is accomplished by applying a predetermined threshold value to the greyscale image. To achieve this in ImageJ, select Image-Adjust-Threshold from the menu. If all the data is missing, the threshold value can be manually modified. It separates the entire image into various parts. Since light cannot penetrate cracks, the pixels there are darker. By thresholding, all of the pixels in an image were converted to either 0-a black pixel or 255-a white pixel. A pixel will turn black if its value is below the threshold value, while pixels with values higher than the threshold value will turn white.

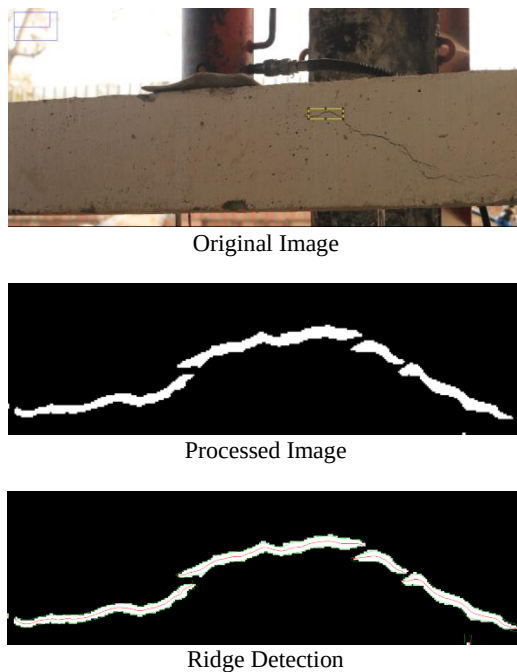


Figure 10. Shows result of image processing

Binary Processing

Any remaining errors in the image after segmentation, such as 'salt in pepper' in the cracks or "pepper in the salt" in the intact soil, can be fixed using some elementary binary operations. To further process the images as binary, use ImageJ's Process-Binary-Make binary command. Each pixel is replaced by erode with the lowest (lightest) value found in a 3*3 vicinity. It successfully gets rid of pixels from the margins of dark things. Each pixel is replaced with Dilate with its highest (darkest) value within a 3*3 neighborhood. Black object edges can be efficiently pixelated with this technique. When

using OPEN, individual pixels are removed and objects are smoothed using the ERODE and DILATE operations. CLOSE smoothes out objects and fills in small gaps by performing a DILATE operation followed by an ERODE action. Close operations can result in the loss of some important data, therefore despeckle median filter operations can take their place (R. Auvray, 2014). The median value in each pixel's 3*3 neighborhood is substituted for by this filter. Flow diagram and result of image processing are shown in Figure 9 and Figure 10 respectively.

Results and Discussion

Cylinders

Compressive and tensile strength of concrete were found from cylinder test.

Table 4. Shows compressive and tensile strength of concrete

Curing Time (Days)	Curing Type	Avg. Compressive Strength (MPa)	Avg. Calculated Tensile Strength (MPa)
14	Water	15.34	2.35
28	Water	21.25	2.77
44	Water	23.32	2.90
44	Paint	21.35	2.77
44	Air	18.39	2.57

Table 4 shows that compressive strength of concrete at 44 days is higher for water curing samples and lower for air curing samples and paint curing is between air and water curing. This variation is because of moisture loss in different curing types.

Shrinkage Prisms

After 14 days of water curing, shrinkage was measured from day-16 to day-44 for three (03) sets of samples. Types of shrinkage prisms are shown in Table 5.

Table 5. Shows types of shrinkage prisms

Set No	Sample No	Curing Type
Set-1	Sample-1 and Sample-2	14 days water + 30 days paint
Set-2	Sample-3 and Sample-4	14 days water + 30 days air curing
Set-3	Sample-5 and Sample-6	44 days water curing

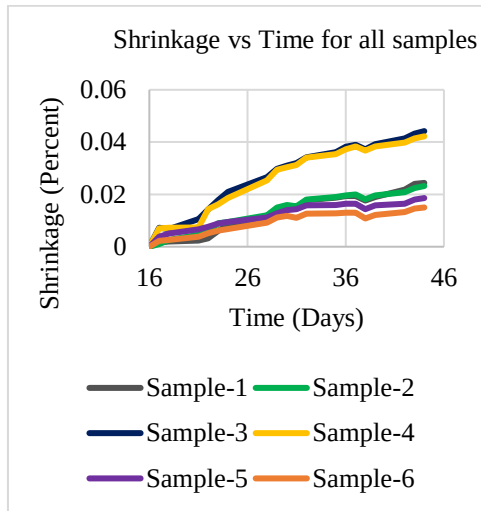


Figure 11. Shows the variation of shrinkage with time for all samples

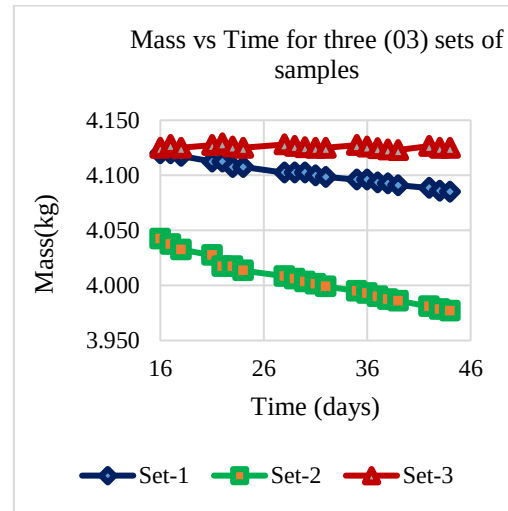


Figure 12. Shows the variation of mass with time for three (03) sets of samples

Table 6. Shows final shrinkage of sets

Set No	Final Shrinkage (Percent)
Set-1	0.024
Set-2	0.043
Set-3	0.017

Figure 11 shows that the shrinkage variation between samples in a set is almost similar. Figure 11 and Table 6 show that shrinkage is highest for Set-2 because of huge loss of moisture from concrete and shrinkage is lowest for Set-3 because of small loss of moisture from concrete. Shrinkage for Set-1 is close to Set-3, that means loss of moisture from concrete has been reduced by the effect of painting.

Mass of each shrinkage prism was also recorded to justify the effectiveness of painting. Figure 12 shows the variation of mass with time for three (03) sets of samples. Figure 12 also shows that mass is almost constant for Set-3 because of very little loss of moisture under water and the rate of mass loss is higher for Set-2 and lower for Set-1 because of painting. That also shows painting cannot control moisture loss fully but control a lot. So “Acrylic Plastic Emulsion Paint” is effective for controlling loss of moisture.

Beams

Deflection

Deflections for simply supported beams have been measured experimentally and calculated using code- AS 3600-2018, ACI 318-14 and Eurocode 2:2004 (CEN, 2004; ACI Committee, 2014; Aggregates Australia, 2018).

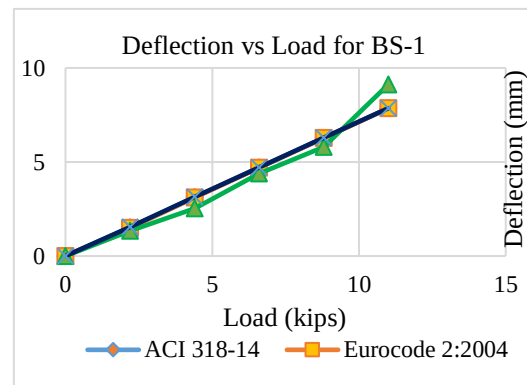


Figure 13. Shows the variation of deflection with load for BS-1

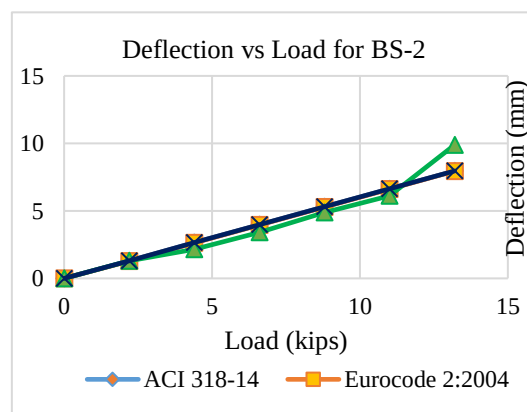


Figure 14. Shows the variation of deflection with load for BS-2

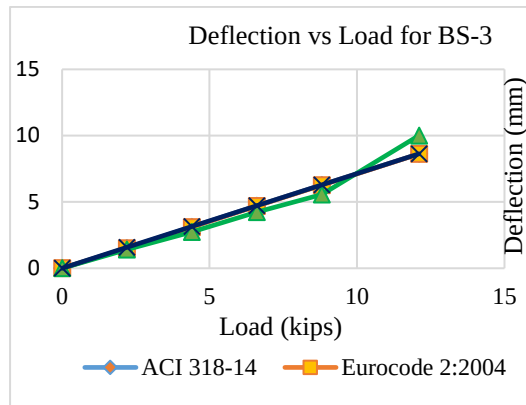


Figure 15. Shows the variation of deflection with load for BS-3

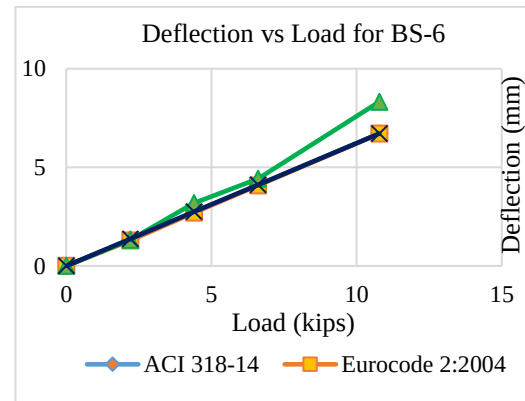


Figure 18. Shows the variation of deflection with load for BS-6

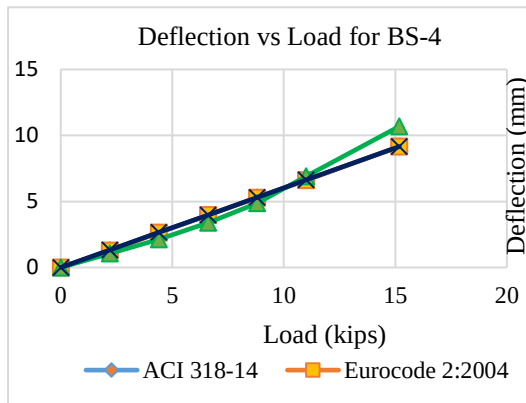


Figure 16. Shows the variation of deflection with load for BS-4

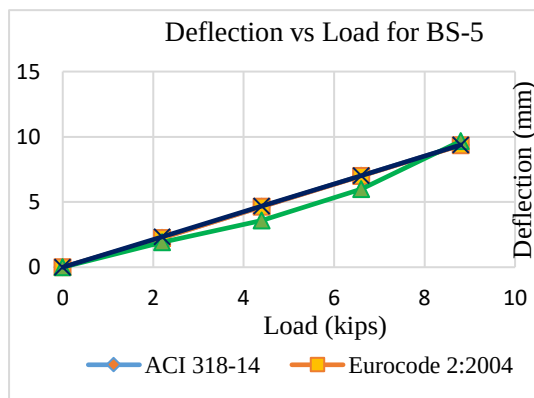


Figure 17. Shows the variation of deflection with load for BS-5

Figure 13 to Figure 18 show the variation of deflection with load for different samples by using code- AS 3600-2018, ACI 318-14 and Eurocode 2:2004. These show that the variation of deflection with load is almost same for ACI 318-14, AS 3600-2018 and Eurocode 2:2004. AS 3600-2018 has considered shrinkage, so its values are little higher than ACI 318-14 and Eurocode 2:2004. But as the shrinkage values are so small, that's why it shows no significant differences with ACI 318-14 and Eurocode 2:2004. ACI 318-14 and Eurocode 2:2004 also don't show any significant differences between them.

Figure 13 to Figure 18 also show the variation of deflection with load for calculated and experimental results. These show that there is little variation between calculated and experimental results, because of dial gauge was not perfectly zero in some cases and result would be more accurate if digital dial gauge used instead of analog dial gauge.

Crack

Cracks for all the beam samples were calculated using Eurocode 2:2004 and ACI 224.1R-07 and measured by using image processing technique through ImageJ (CEN, 2004; 224.1R, 2007).

Table 7. Shows theoretical 1st cracking loads of samples

Sample No	Load (kips)
BS-1	4.48
BS-2	4.45
BS-3	4.48
BS-4	4.45
BS-5	4.43
BS-6	4.50

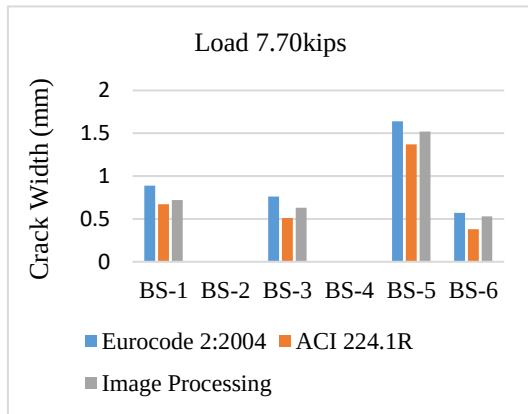


Figure 19. Shows the variation of crack width with samples for 7.70kips load

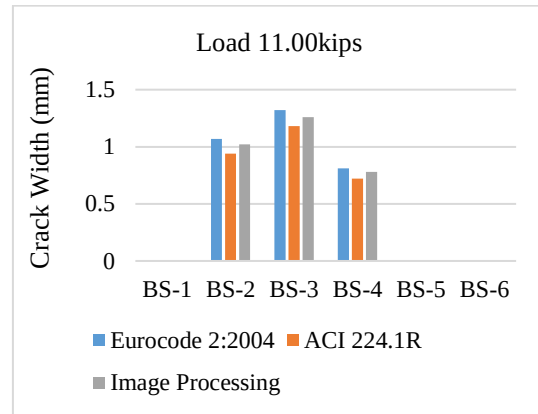


Figure 22. Shows the variation of crack width with samples for 11.00kips load

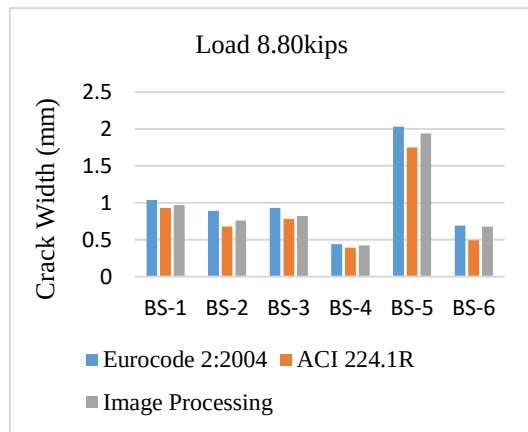


Figure 20. Shows the variation of crack width with samples for 8.80kips load

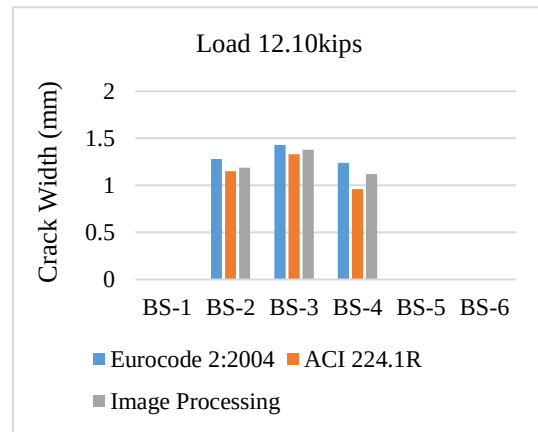


Figure 23. Shows the variation of crack width with samples for 12.10kips load

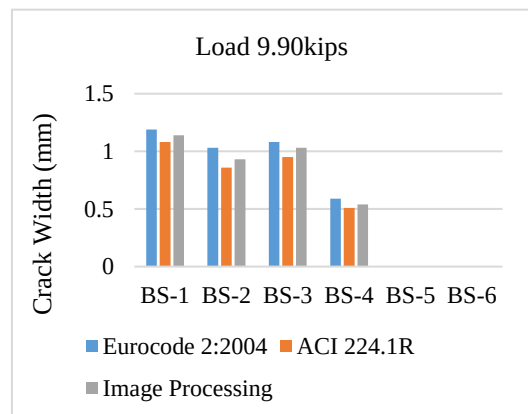


Figure 21. Shows the variation of crack width with samples for 9.90kips load

Figure 19 to Figure 23 show the variation of crack width with samples for different loads. These figures show that crack width value of image processing is between the values of Eurocode 2 and ACI 224.1R-07, so image processing gives a better result and some width were checked through microscopic results and found almost similar.

Image processing is very much helpful in crack detection as the obtained value is almost same with the calculation value. For large structure like bridge, it is difficult to observe and estimate the crack width, length and spacing by visual inspection. An unmanned aerial vehicle can be used to obtain picture and the identification and determination of dimension of crack can be done by image processing.

Conclusions

The aim of this study was to measure deflections of simply supported beams experimentally and calculate deflections of simply supported beams using code- AS 3600-2018, ACI 318-14 and Eurocode 2:2004 and also compare among them, moreover compare deflections of simply supported beams between experimental and calculation results. Also measure shrinkage of beams in different curing conditions and justify the effectiveness of Painting which was introduced for moisture control. Moreover, to determine crack width for failure of concrete by using image processing technique and calculate crack width of simply supported beams using Eurocode 2:2004 and ACI 224.1R-07 and compare between them and also compare the results from image processing and theoretical calculations. From this study the following conclusions can be drawn:

Deflections of simply supported beams using AS 3600-2018, Eurocode 2:2004 and ACI 318-14 are almost same.

Deflections of simply supported beams from experimental and calculation results using AS 3600-2018, Eurocode 2:2004 and ACI 318-14 are very close.

The shrinkage of beams in different curing conditions differs and “Acrylic Plastic Emulsion Paint” can be used for controlling loss of moisture from structural elements.

Crack width from image processing and theoretical calculations using Eurocode 2:2004 and ACI 224.1R-07 are very close.

Image processing is a very effective technique in the study of crack in concrete and for automatic detection “Ridge Detection” plugin is very helpful. Recommendations from this study are as follows-

ACI 318-14 and Eurocode 2:2004 should consider shrinkage effect in the calculation of beam deflection to obtain the exact result with AS 3600-2018.

Digital dial gauge should be used instead of analog dial gauge for more accurate deflection results.

Other types of paints except “Acrylic Plastic Emulsion Paint” can be used to check the effectiveness for controlling loss of moisture from structural elements.

Other image related software should be used to test for further development of automatic crack detection.

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