Application of 2-dimensional Digital Image Correlation for mapping bond strain and stress distribution in concrete

REZA AGHLARA

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Civil-Structure)

Faculty of Civil Engineering
University Technology Malaysia

July 2010

I dedicate this work to my beloved,

Granny,

Parents

And my brother

ACKNOWLEDGMENT

I would like to express a sincere appreciation to supervisor of this project, Dr. Redzuan Abdullah for his patience, useful guidance and time which have been contributed in this research that without his assistance this work would not have been the same as presented here.

Technical Staff of material and structure laboratory at UTM should also be recognized for their assistance during experimental work, especially Mr. Raja Ezar Ishamuddin Raja Abdul Latif for endurance and great attitude.

Thanks to my friends and fellow postgraduate students for their help, view and tips at various occasions.

Also I wish to express my appreciation to those who have given me either direct or indirect assistance in this project.

I am grateful to all my family member for their support, especially my mother and father for always being there for me.

Good luck to each of you in your future.

ABSTRACT

Buildings and civil engineering structures nowadays are mostly constructed using reinforced concrete. In the reinforced concrete, one of the fundamental factors that influence its strength is bond between bars and concrete. In the reinforced concrete, one of the fundamental factors that influence its strength is bond between reinforcement bars and concrete. A lot of research on concrete anchorage bond had been carried out since 1913. However, till today the exact behaviour of anchorage bond in reinforced concrete is not very clear. An attempt to trace the stress contour in concrete due to the presence of anchorage bond had been made. Two dimensional digital image correlations were applied to images of pull-out concrete test blocks. Full-field strains contour on the surface of the concrete blocks were obtained at various level of pull-out forces using digital image correlation software. The strains were converted to stresses using plane stress concrete material constitutive equation. The results of this study show that the digital image correlation method is able to trace the stress components in the concrete surface under the influence of anchorage stresses. The distribution of the longitudinal stresses in the concrete surface along the reinforcement length was found to be nonlinear with maximum value occurs near the loading end.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

E	Concrete Module of Elasticity
e_{xx}	Normal Stress in x direction
e_{yy}	Normal Stress in y direction
e_{xy}	Normal Shear Stress
e_1	Major Principle Stress
e_2	Minor Principle Stress
f_c	Compressive Strength of Concrete
F(x,y)	Grey Scale function of reference image
G(x,y)	Grey Scale Function of deformed image
S_x	Normal Stress in x direction
S_y	Normal Stress in y direction
S_{xy}	Normal Shear Stress
U	Horizontal Displacement
V	Vertical Displacement
ν	Poisson Ratio
εxx	Normal Strain in x direction
εyy	Normal Strain in y direction
εxy	Normal Shear Strain
X	Horizontal Coordinates
Y	Vertical Coordinates
Z	Distance between specimen plane and camera lens

CHAPTER 1

INTRODUCTION

1.1 General

As a practical and effective tool for quantitative in-plane deformation measurement of a planar object surface, two-dimensional digital image correlation (2D DIC) is now widely accepted and commonly used in the field of experimental mechanics. It directly provides full-field displacements to sub-pixel accuracy and full-field strains by comparing the digital images of a test object surface acquired before and after deformation.

On the other hand, the importance of the material as reinforced concrete in concrete structures is known to anybody who is involved by construction and civil engineering field. Statistically speaking, in comparison with the steel structures, the number of concrete structures has been growing day by day. So by having these preferences for concrete structures, it is needless to say that every property of this material will have a great importance and extremely worthful to study comprehensively in order to find out exact behavior of that material perfectly. A large number of books and published articles in this area is a good evidence for this claim.

One of the most important features in the reinforced concrete is the bond between bars and concrete that will be studied in this project. The joint behavior of steel and concrete in a reinforced concrete member is based on the fact That a bond is maintained between two materials after concrete hardens. If a straight bar of round section is embedded in concrete, a considerable force is required to pull the bar out of the concrete. If the embedded length of the bar is long enough, the steel bar may yield; leaving some length of the bar in the concrete. The bonding force depends on the friction between steel and concrete, interlocking and chemical adhesion.

1.2 Problem statement

Mathematically and theoretically, the calculation of bond strength has not done yet clearly by consideration of many effective parameters. So the development length that used in practical structures is calculated by the experimental formula in codes. That may cause to use an extra unnecessary length of bar in some cases. In order to have a helpful step and be closer to theoretically solution, having realistic bond stress distribution based on experimental samples will be useful to great extent. Moreover having such distribution, helps us to have high understanding of bond behavior that leads using bars properly in concrete. Having full-field strain and stress measurements of concrete pull-out specimen can be helpful to who are interested in realizing bond behavior precisely and it may change some conception or may find new ideas in the bond field. It is worth to note that finding of strain contour based on theoretical technique as Finite Element Method depends on many factors, and bond simulation cannot be done easily. But 2D-DIC strain analysis is based on experimental work and more reliable. Figure 1.1 shows apparent differences of contour from FEM versus 2D-DIC.

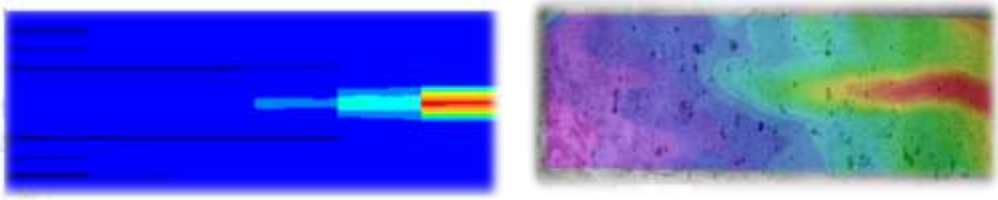

Figure 1.1 The Strain distribution of FEM versus 2D-DIC from left to right respectively

2D-DIC is a new method in the practical area and it is important to researchers to know; How someone can trust to the 2D-DIC?, What's the accuracy rate of this measurement? What's the feature of this method?, What are the requirements for doing this measurement? So, to answer these questions, more study and experiment should have been done in this field.

Moreover, 2D-DIC is more economical in comparison with the other common measurement method in lab works. For example, the figure 1.2 shows the configuration of a specimen has been done recently for bond study purpose. As it can be observed about 26 strain gages have been used for this research. With assuming 100 MR per gage, the total gage expense will be 2600 MR just for one specimen. In case of being capable of using 2D-DIC there is no need for such a high expenses.

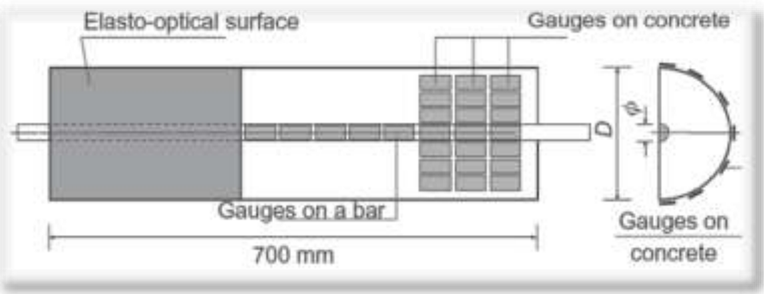

Figure 1.2 Common Specimen with strain gages for study of bond [5]

1.3 Aim and Objective

Two objectives are defined for this project as following;

1- Application of 2-Dimensional Digital Image Correlation (2D-DIC) for finding motion and deformation on concrete pull-out specimen.

2- Mapping bond strain and stress component distribution on front plane of concrete pull-out specimen.

As shown in figure 1.3, the reaction of subjected tensile force on reinforcement are inclined reaction that can be presented with two components, parallel and normal to bar axes. Mapping of distribution of these 2 components on the face of specimen by 2D-DIC are objective of this research.

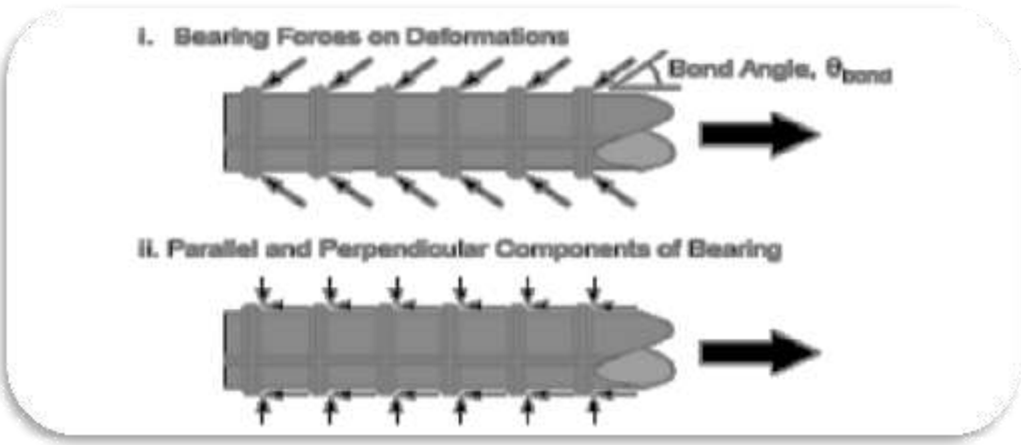

Figure 1.3 Bond Stress Components around reinforcement [6]

1.4 The Scope of study and Limitation

Generally for mapping stress distribution we have three methods based on theoretical, software and lab experiments. Theoretical method cannot be an accurate reference because it is an approximate method based on several hypotheses and also there are some unrevealed factors that cannot be considered in theoretical method such as direction of concrete pouring. In this project theoretical and software result for distribution is not the work scope.

Real bond stress distribution of a concrete pull-out specimen is 3-dimensional around the bar in concrete. 2D-DIC is capable to measure deformation on a plane. So the stress distribution due to the bond on the surface of the specimen will be calculated in this project.

The bond strength depends on a lot of parameters as concrete property, bar diameter and so on. The purpose of this project is mapping of stress distribution of bond and the effect of parameters to the bond is not the scope of the work. The ultimate bond strength may be able to find with 2D-DIC but it needs different configuration of specimen and it is not intention of this project.