# A Decision Support System for Condition Assessment of Concrete Buildings

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# Decision Support System (DSS)

- DSS is a windows application which provides the engineer/respondent with advice or recommendations on the designated domain.
- In this work the domain is diagnosis of distress in concrete building.
- This domain is well represented and saved in the form of a knowledge base.
- The DSS is named by the author as **ConAsCon-16**.
- Development of ConAsCon-16 is motivated by a need to transfer knowledge from technical books and experts and to make them available to practicing engineers in a GUI (Graphical User Interface) form.

# Distress in Concrete

- Concrete is one of the most versatile and durable construction material used worldwide.

- During its service life, concrete undergoes several deteriorations.

- The damage can be categorized in terms of
    - Damage types
    - Causes and mechanism of attack
    - Frequency of defect
    - Kind of deficient structures
    - financial loss due to different defects
    - Amount and repair measures
- This work focuses on *Damage type and Causes and mechanism of attack.*

# Damage Types

- The damage type can be broadly classified as Scaling, Spalling, Curling and Cracking.
- Scaling, Spalling and Curling are due to material damage, such as from lack of control and poor construction practice.
- While Cracking may be due to a structural cause like overloading or Non-structural cause like drying shrinkage, thermal contraction, restraint, subgrade settlement.
- *Diagnosis of distress caused by cracking in concrete is being addressed in this work*.

# Crack Forms

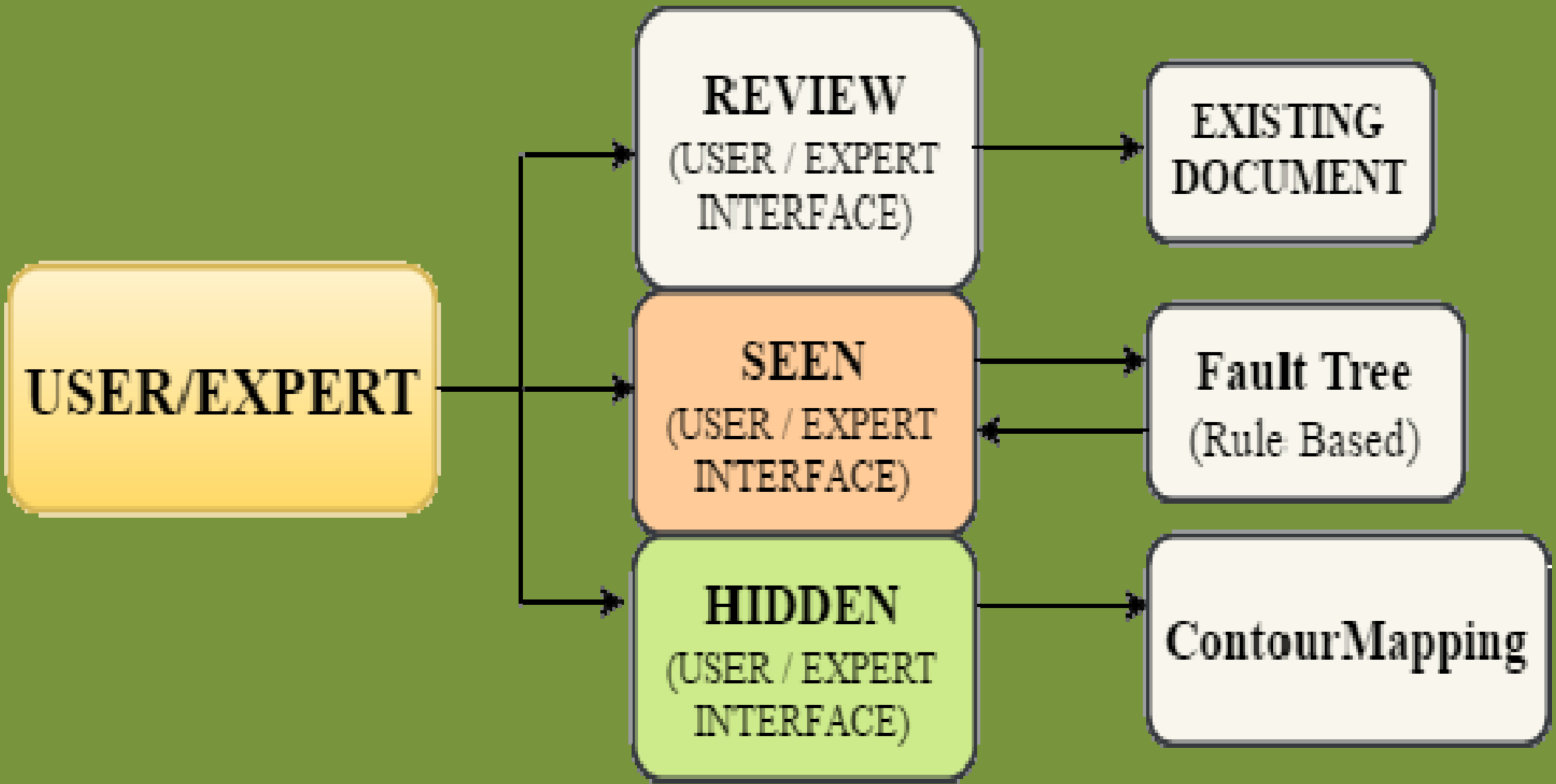
- Cracking can be divided into Eight groups according to (PCA 2001, ACI 2007). The classification is based on shape/form of cracks.

| Crack form | Definition |
|---|---|
| **D-Cracking** | It begins in certain types of susceptible coarse aggregate, caused by repeated freezing and thawing after absorbing moisture. |
| **Random** | It shows several cracks in a reinforced concrete slab without any regular pattern. |
| **Diagonal** | It is caused by loss of foundation support, base erosion and shear stresses, at about 45 degrees to the natural axis of a concrete member |
| **Map** | It is fine openings on concrete surfaces in the form of a pattern |
| **Crazing** | It is fine and random cracking extending only through the surface |
| **Longitudinal** | It develop parallel to the long direction of the member |
| **Transverse** | It develop at right angles to the long direction of the member |
| **Crack at joints** | They are Cracks either at or in the vicinity of transverse and longitudinal joints |

# Need of ConAsCon-16

- Understanding the mechanism of each crack and diagnosing the causes with mentioned factors is very bulky, time consuming , occasionally vague and indirect.
- The user/engineer needs to review extensive sources, gather more additional information and use expert's skills to analyze the cause of distress.
- Hence the development of a DSS like ConAsCon-16 helps the user in faster diagnosis.

# ConAsCon-16




GLOBAL ARCHITECHTURE OF ConAsCon-16

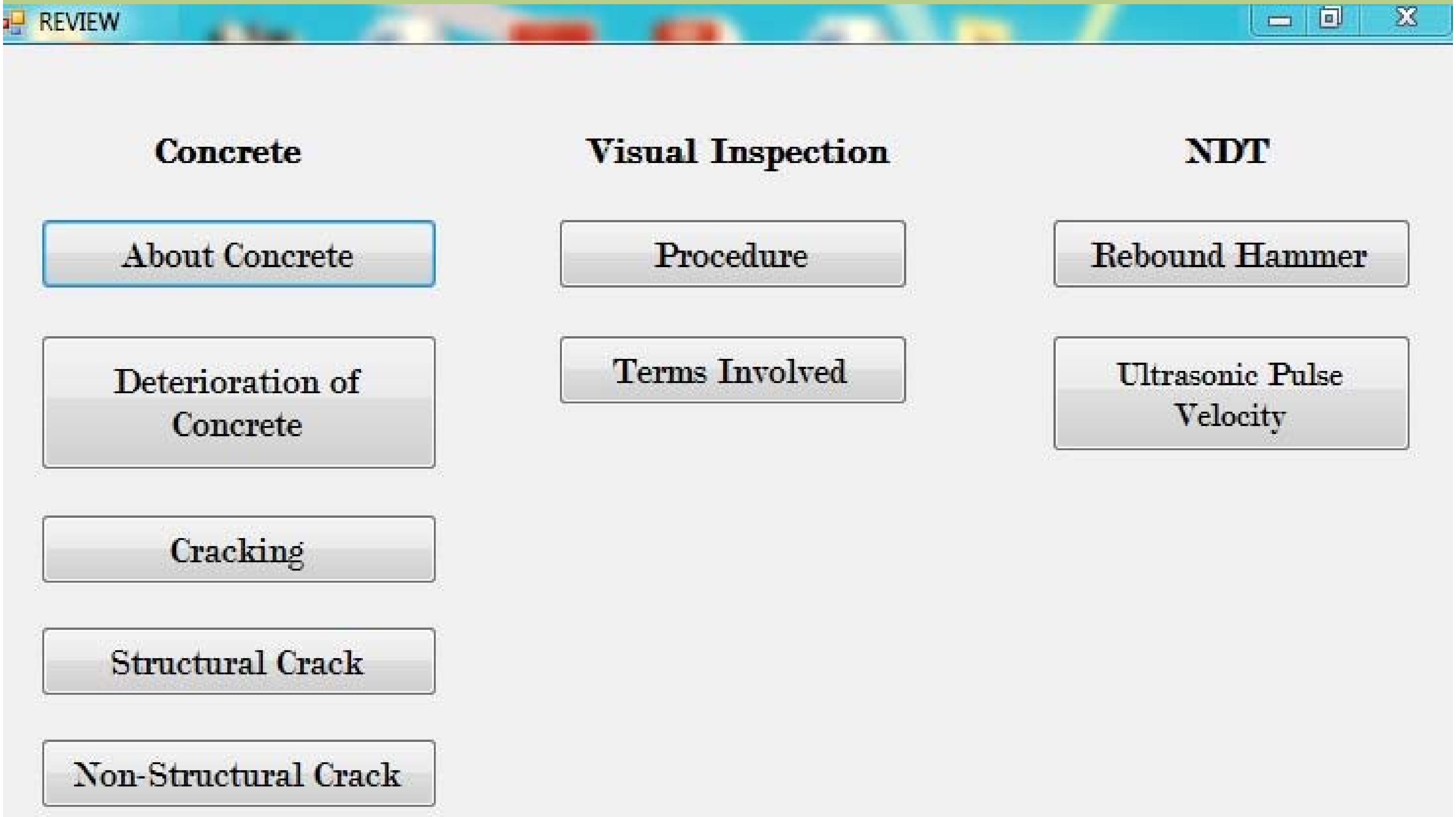
# ConAsCon-16

- It has three modules – REVIEW, SEEN, HIDDEN
- **REVIEW** helps the user/engineer to review the existing documents in the system in order to gain knowledge in the field of concrete distress, Visual Inspection, and Non-Destructive Testing.
- **SEEN** consists of set of Fault Tree Algorithm (FTA) which assists the engineer in taking decision regarding the cause of deterioration in concrete.
- The problem unsolved with the module SEEN are advised for undergoing NDT.
- **HIDDEN** generates a contour map for the results obtained from NDT- Rebound Hammer and Ultrasonic Pulse Velocity field test.

# Methodology

- Data Acquisition : The data available for all possible cracking in concrete structures are collected. Available literatures such as ACI manuals of concrete practice and RILEM publications and the data provided in internet are all useful tools in this respect.
- Grouping of crack : The crack data collected is then grouped according its shape/form.
- Developing Fault tree: The causes of each crack form are drawn as a fault tree structures.
- Contour Map: the results obtained from NDT field test are incorporated to generate a contour map.
- Creating GUI : The data are incorporated in a computer software that can be easily applied by engineers.

# Screenshot of Module – 'REVIEW'



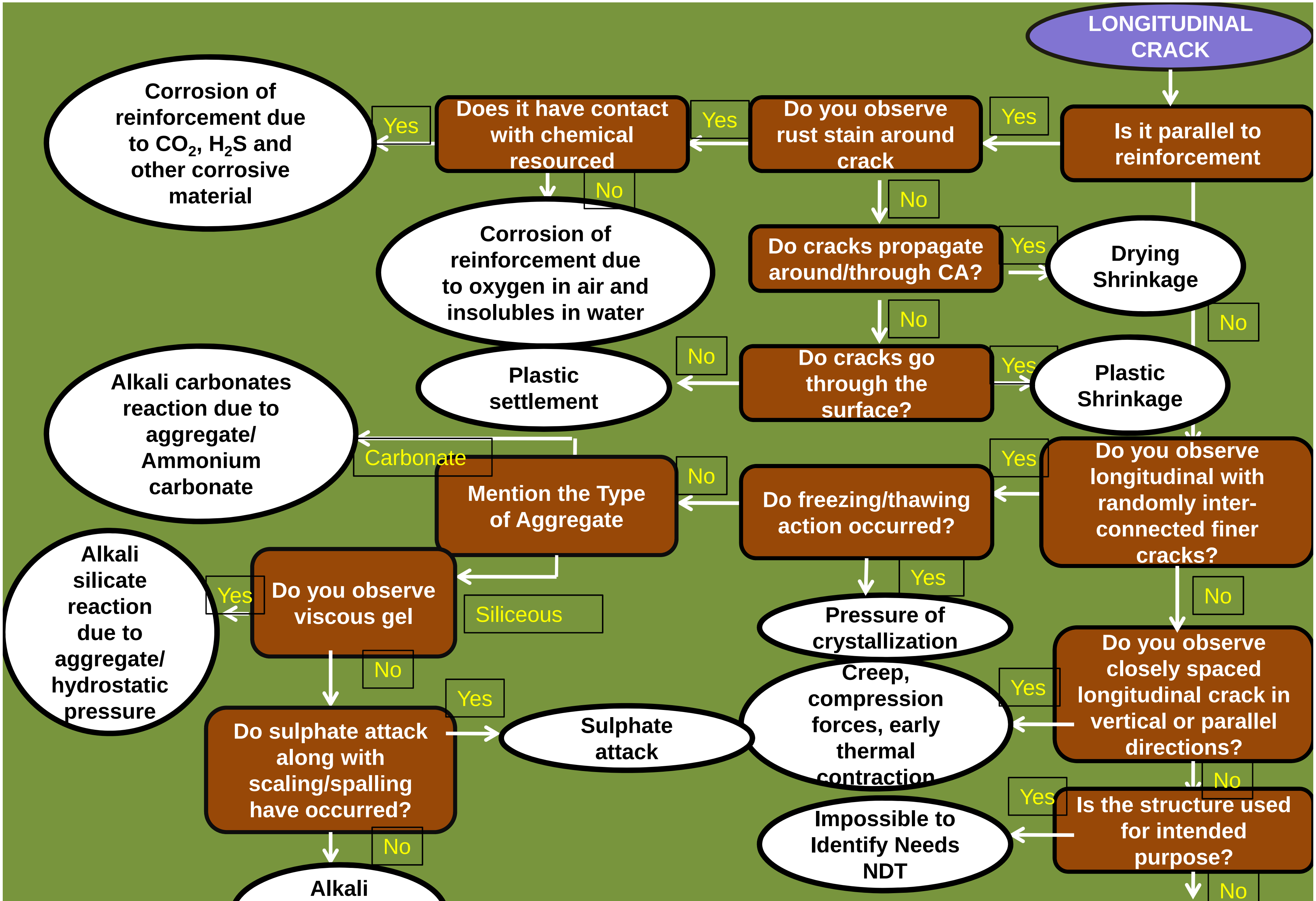

On selecting the icon, the data related to it will be displayed as a adobe document, which will be useful for the user to brush up his knowledge.

# SEEN

- The Eight crack forms discussed earlier are used to develop fault trees to support the module SEEN.
- As a sample, fault tree for longitudinal cracking is shown in next slide.
- The tree begins with a question about the orientation of the crack.
- The question is “Is it parallel to the reinforcement?”
- There are two answers for this question.
- If the answer is yes, then another question will be asked about rust stain.
- If rust stain is seen near the crack, then reinforcement corrosion will be the cause.

# SEEN

- ❑ However, different types of corrosion may happen and the remaining questions will provide answers for type of corrosion.
- ❑ All of these fault trees are put in a computer program with Graphical User Interface (GUI).
- ❑ The user/engineer can interact with the program to obtain the cause of a particular crack form.
- ❑ For the unsolved distress the user is advised to undergo NDT.
- ❑ In the subsequent module - HIDDEN the interpretation for the results of NDT is made easy by generating Contour map.


LONGITUDINAL CRACK
Is it parallel to reinforcement
Yes
Do you observe rust stain around crack
Yes
Does it have contact with chemical resourced
Yes
Corrosion of reinforcement due to $CO_2$, $H_2S$ and other corrosive material
No
Corrosion of reinforcement due to oxygen in air and insolubles in water
No
Do cracks propagate around/through CA?
Yes
Drying Shrinkage
No
No
Do cracks go through the surface?
Yes
Plastic Shrinkage
No
Plastic settlement
Do you observe longitudinal with randomly inter-connected finer cracks?
Yes
Do freezing/thawing action occurred?
Yes
Pressure of crystallization
No
Mention the Type of Aggregate
Carbonate
Alkali carbonates reaction due to aggregate/ Ammonium carbonate
Siliceous
Do you observe viscous gel
Yes
Alkali silicate reaction due to aggregate/ hydrostatic pressure
No
Do sulphate attack along with scaling/spalling have occurred?
Yes
Sulphate attack
No
Alkali Aggregate Reaction
No
Do you observe closely spaced longitudinal crack in vertical or parallel directions?
Yes
Creep, compression forces, early thermal contraction
No
Is the structure used for intended purpose?
Yes
Impossible to Identify Needs NDT
No
Overloading

# HIDDEN

- This module helps the user/engineer to interpret the NDT results.
- As we all know NDT is testing without damaging the concrete.
- By Contour mapping technique - Rebound Hammer and Ultrasonic Pulse Velocity data can be interpreted, which may be very useful in concrete analysis.
- In the contour map ‘X’ and ‘Y’ co-ordinate depict the position of UPV probes/Rebound Hammer and ‘Z’ depicts the UPV value/Rebound Number.
- In addition to contour mapping the module – HIDDEN is facilitated with the provision for calculating compressive strength of concrete from UPV and Rebound values.

# Validation – 'SEEN'

**Fig a. Longitudinal crack in beam**

**Fig b. Diagonal crack in Wall from opening**

**Fig c. Random crack in Floor slab**

**Fig d. Transverse crack in beam**

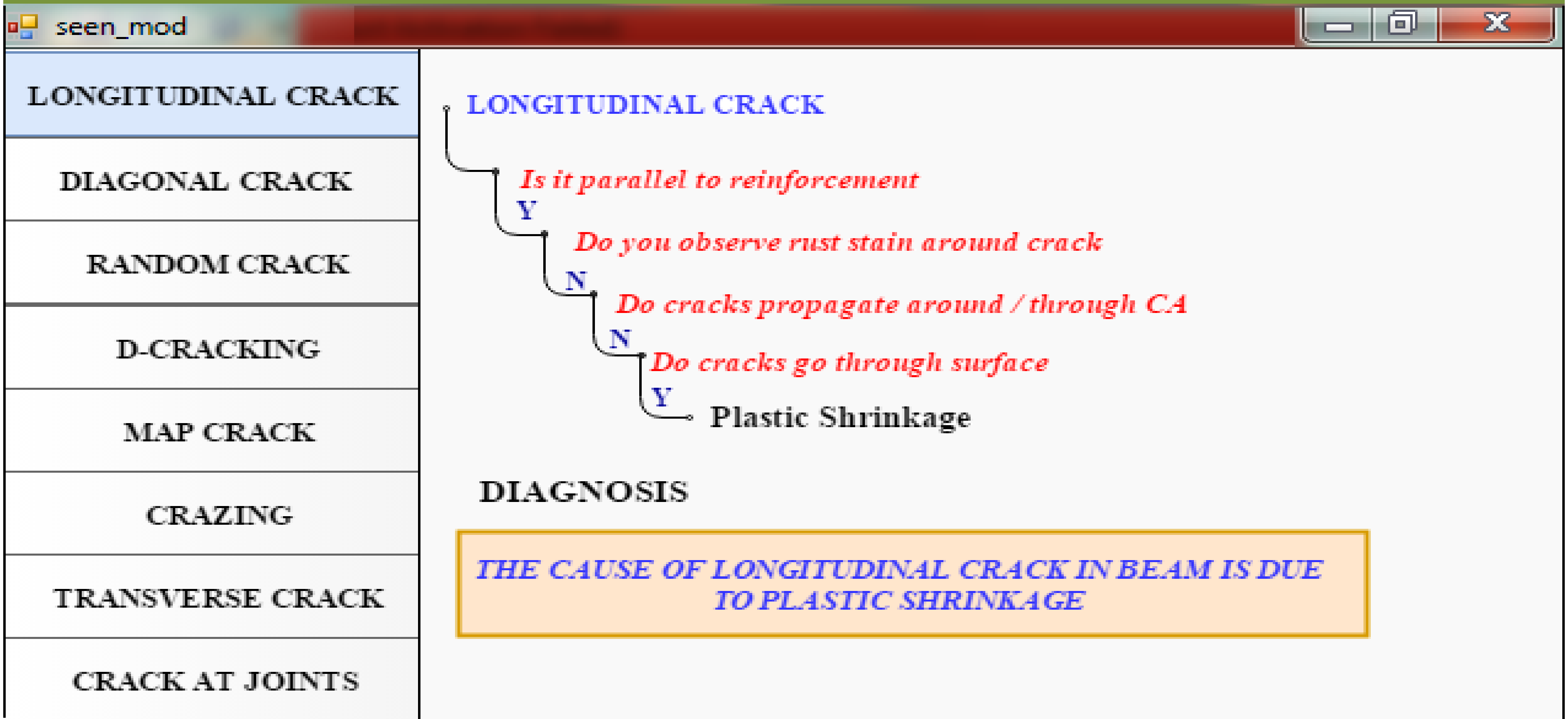
# Validation – 'SEEN'

| S.No | Crack Type | Member Type | Fig. No. | Symptoms observed | Diagnoses from ConAsCon-16 |
|---|---|---|---|---|---|
| 1 | Longitudinal Crack | Beam | a | • Crack parallel to reinforcement.<br>• Rust stain observed around the crack.<br>• No contact with chemical resources. | **Corrosion of reinforcement due to oxygen in air.** |
| 2 | Diagonal Crack | Wall | b | • The crack starts from a reentrant corner (near opening).<br>• It runs throughout the wall.<br>• It doesn't have split ends.<br>• Wider crack | **Due to ground motion or Instable soil strata below the building.** |

# Validation – ‘SEEN’

| S.No | Crack Type | Member Type | Fig. No. | Symptoms observed | Diagnoses from ConAsCon-16 |
|---|---|---|---|---|---|
| 3 | Random Crack | Slab | c | • Have randomly interconnected finer cracks.<br>• No sign of bulging | **Drying Shrinkage** |
| 4 | Transverse Crack | Beam | d | • Grouping of cracks<br>• It runs from soffit to the centre of beam.<br>• Doesn’t have split ends | **Inability of beam to resist flexural load.** |

# Validation – 'SEEN'

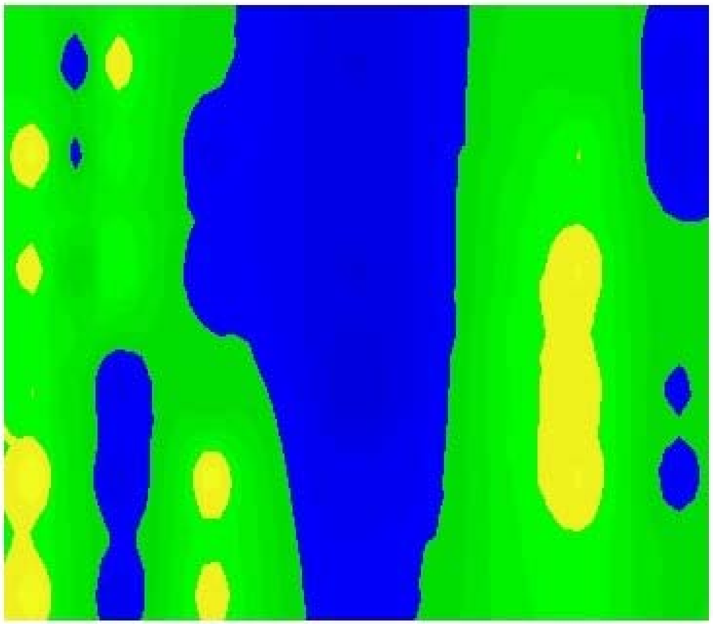



Screenshot of ConAsCon -16 program page for module -SEEN

# Validation – 'HIDDEN'

Contour Graph

**CONTOUR MAP**



Enter No of Inputs 65 Submit Clear

| Points | X - Value | Y - Value | Z - Value |
|---|---|---|---|
| Point 1 | 0 | 0 | 29 |
| Point 2 | 90 | 0 | 21 |
| Point 3 | 180 | 0 | 30 |
| Point 4 | 270 | 0 | 12 |
| Point 5 | 350 | 0 | 26 |
| Point 6 | 440 | 0 | 35 |
| Point 7 | 0 | 90 | 24 |
| Point 8 | 90 | 90 | 22 |
| Point 9 | 180 | 90 | 26 |
| Point 10 | 270 | 90 | 23 |
| Point 11 | 350 | 90 | 16 |
| Point 12 | 440 | 90 | 24 |
| Point 13 | 530 | 90 | 30 |
| Point 14 | 620 | 90 | 25 |

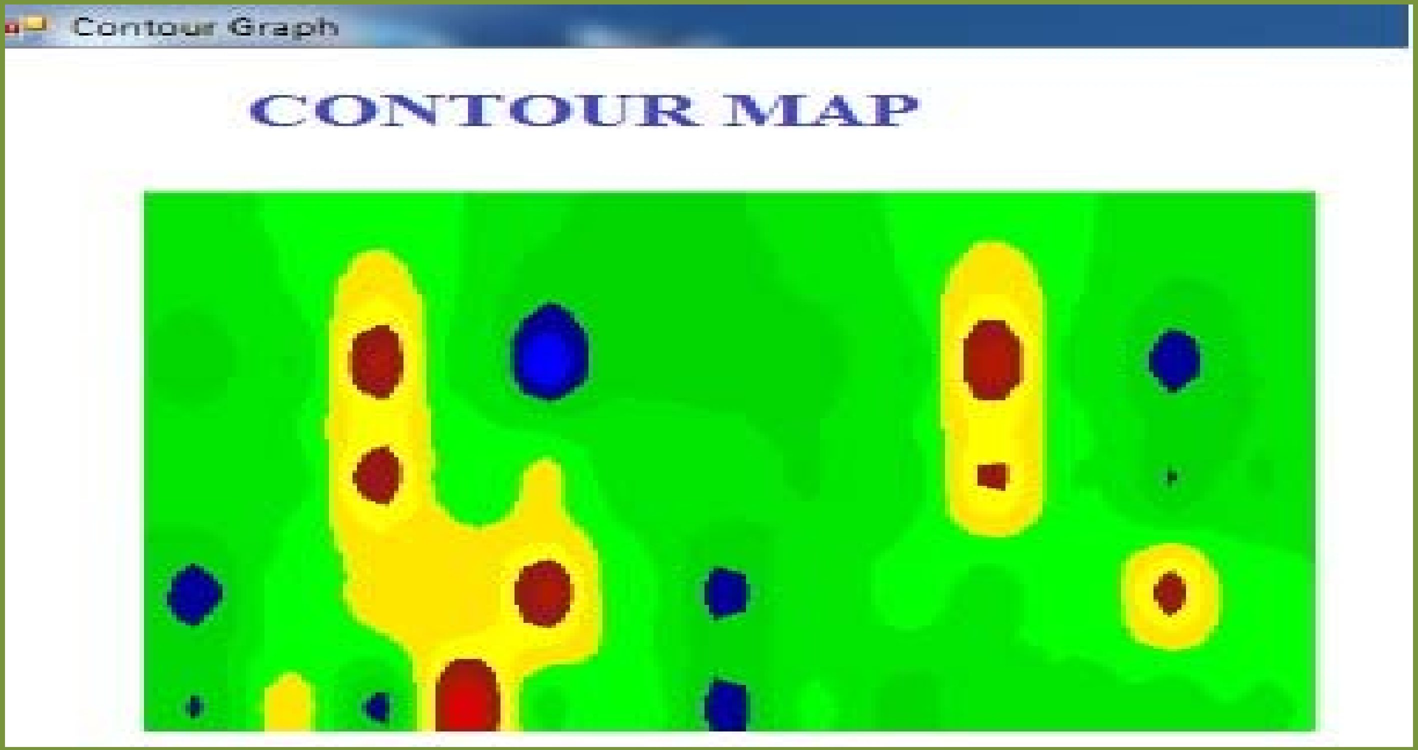
Collect Values

X : 1070 Y : 350 Z : 25 ADD

Print Draw Contour Graph

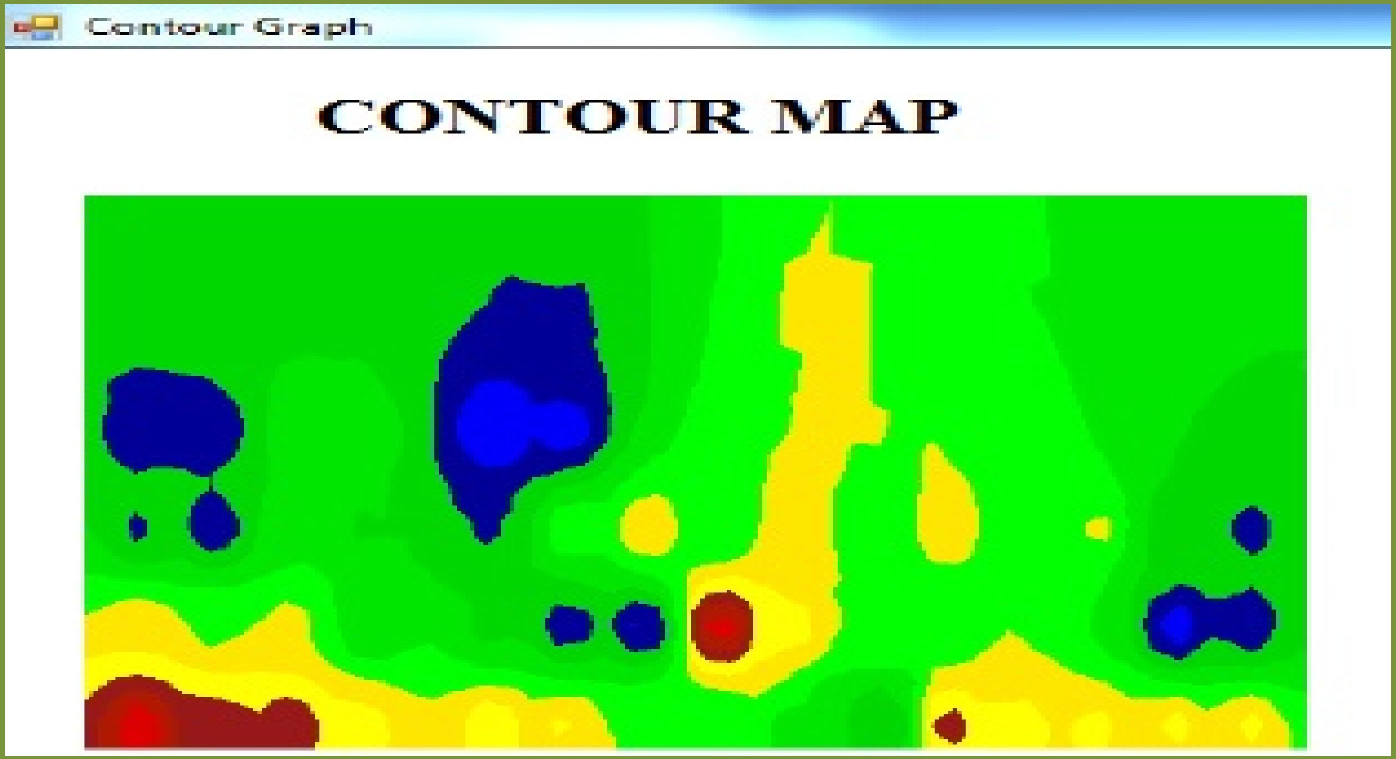
Screenshot of ConAsCon -16 program page for generating Contour Map

# Rebound Hammer – Contour Map



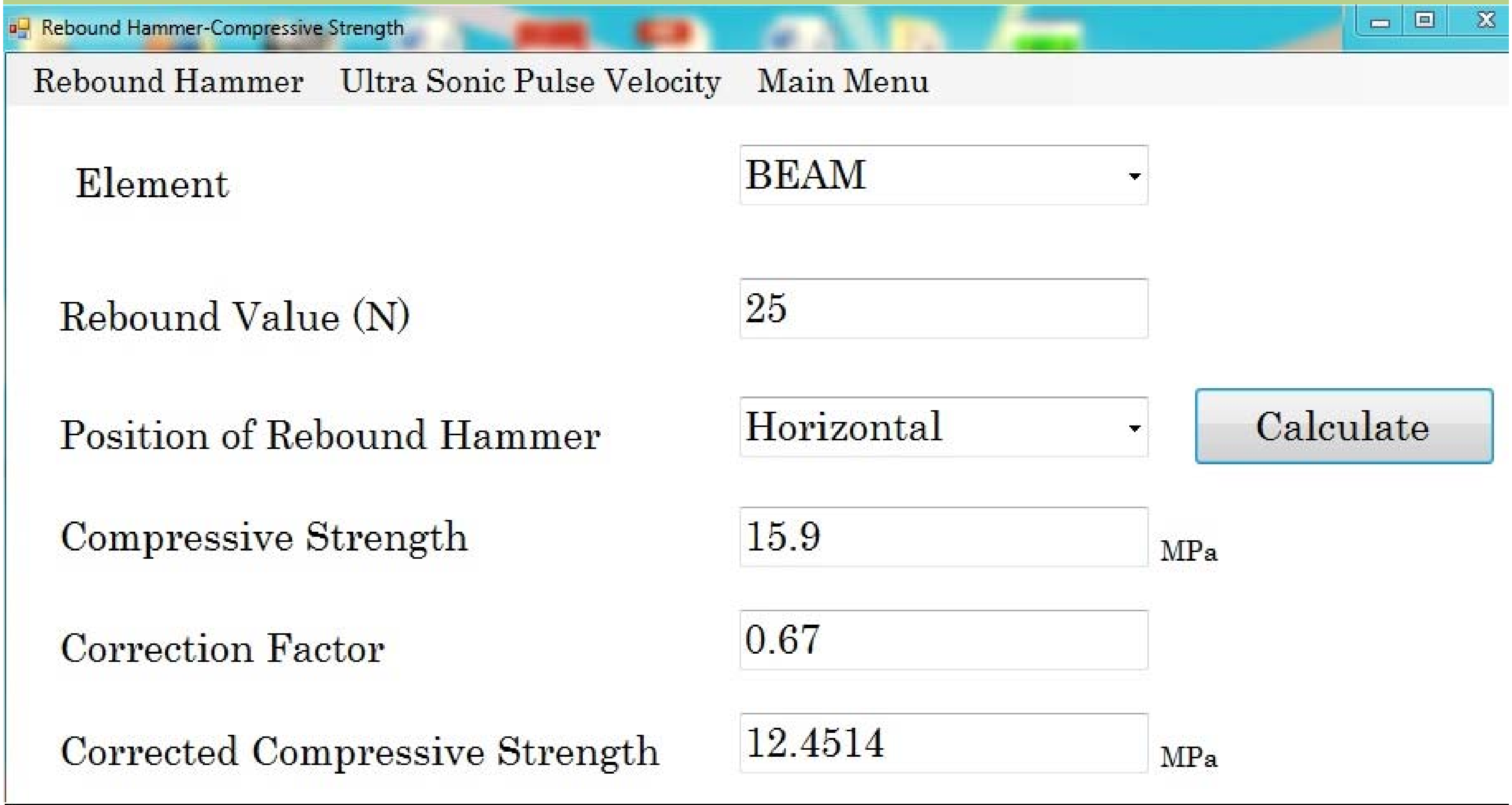

- The Contour map shows where readings are higher or lower.
- Points of  no color variations show that the concrete is homogeneous.
- Hot color indicates point of low energy rebound or softer surface.
- The image shows that the most defects are located on left side.
- The Rebound Hammer Values are taken from literature work of Hannachi S 2012 [7]

# Ultrasonic Pulse Velocity– Contour Map




- The hotter color in the contour graph indicates points of low UPV value or evidencing presence of voids and colder color indicate high UPV values or more compact zones.
- The image shows the wide spread of voids in the concrete beam.
- The UPV values are taken from the literature work of Tumendemberel B 2002 [18]

# Rebound Hammer – fck




- Here a correction factor is incorporated as the manufacturer provided graph become disproportionate for concrete of age above 90 days.
- The correction factor is referred from Ferhat Aydin 2010 [6]

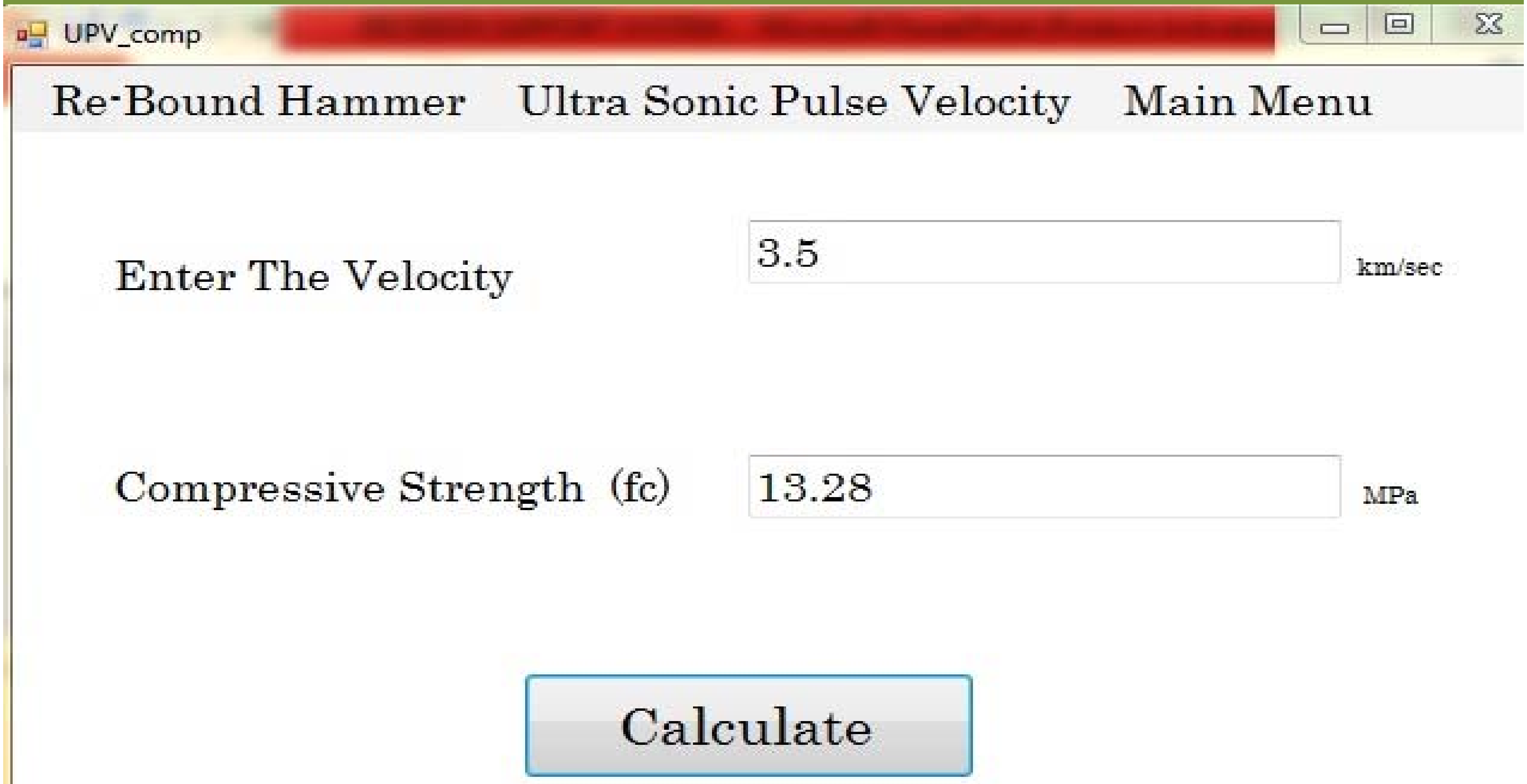
# Rebound Hammer – fck

- The results of ConAsCon-16 is validated with the data are taken from literature work of Jaggerwal.H 2014 [8]

| Location in Beam | Direction | Rebound Value | Compressive Strength | |
|---|---|---|---|---|
| | | | ConAsCon-16 | Literature |
| 1.1 | Horizontal | 43 | 44.01 | 46 |
| 1.2 | Horizontal | 46 | 49.54 | 51 |
| 1.3 | Horizontal | 51 | 58.62 | 61 |
| 1.4 | Horizontal | 53 | 57.98 | 65 |
| 1.5 | Horizontal | 57 | 51.5 | 53 |

- Since the compressive strength value of the program is with a correction factor, there is a slight variation in the compressive strength value.

# UPV– fck




- The values got from the program ConASCon-16 is in close proximity to those from the literatures.

# UPV– fck

- The results of ConAsCon-16 is validated with the data are taken from literature work of Tumendemberel B 2002 [14]

| Location in column | UPV Values (m/sec) | Compressive Strength | |
|---|---|---|---|
| | | ConAsCon-16 | Literature |
| A1 | 3359 | 10.48 | 9.96 |
| A2 | 3565 | 12.19 | 11.15 |
| A3 | 3600 | 14.17 | 13.81 |
| A4 | 3733 | 9.87 | 10.93 |

- The values got from the program ConASCon-16 is in close proximity to those from the literatures.

# UPV– Vertical crack depth

The results of ConAsCon-16 is validated with the data are taken from literature work of Kumar A S [11]

| X (mm) | T1 (µs) | T2 (µs) | Crack Depth calculated from ConAsCon-16 (mm) | Actual Crack Depth from Literature (mm) |
|---|---|---|---|---|
| 50 | 60 | 35 | 69.62 | 70 |
| 80 | 65 | 45 | 62.54 | 68 |
| 80 | 58 | 34.5 | 54.05 | 60 |
| 50 | 91.3 | 36.5 | 114.63 | 115.5 |

- When the distance between the transducers is large the wave travels through the concrete and does not diffract.
- Hence for larger values of x we don't get accurate results.

# UPV– Horizontal crack depth

The results of ConAsCon-16 is validated with the data are taken from literature work of Kumar A S [11]

| X (mm) | V(m/sec) | T (µs) | Crack Depth calculated from ConAsCon-16 (mm) | Actual Crack Depth from Literature (mm) |
|---|---|---|---|---|
| 50 | 3627 | 35.7 | 59.75 | 50 |
| 80 | 3627 | 55.8 | 92.95 | 50 |
| 80 | 4222 | 66.1 | 133.68 | 100 |
| 50 | 4222 | 47.1 | 96.23 | 100 |

# Conclusion

- ConASCon-16 Decision Support System was developed for condition assessment of concrete structure.
- It includes guidance for visual inspection and provides a simple interpretation strategy for Non-destructive testing.
- In **SEEN** module all possible cracking on concrete structures and their causes were listed.
- Then, a set of eight fault trees were developed and the most important fault tree is presented in the paper.
- In **HIDDEN** module, interpreting strategy of Rebound Hammer and Ultrasonic Pulse Velocity were explained.

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# THANK YOU !!