Assessment and Rehabilitation of Existing Structures in Jordan

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Abstract*:** Buildings and structures are getting old which is often accompanied by sever condition degradation and hence they need ***assessment and ***rehabilitation***. Furthermore, changes and update of *National Building Codes* including provisions for earthquake resistant design necessitate ***upgrading*** or ***retrofitting*** of unqualified structures, especially buildings, taking in account the latest seismic provisions, theories and methods. In structural sense assessment is a process to determine how reliable the existing structure is able to carry current and future loads and to fulfill its task for a given time period while rehabilitation is an operation to bring a structure to specified safety and performance level. There are a number of approaches and techniques that are used worldwide in the assessment and rehabilitation practices to examine and evaluate different types of structures and in particular concrete and masonry buildings. Rehabilitation of structures is getting more attention and demand in ***Jordan*** and other countries. The main objective of this paper is to present an overview of the current practices in assessment and rehabilitation of existing buildings/structures in ***Jordan***. The paper will focus on explaining the comprehensive methodology/procedure for structural assessment then documenting the locally applied traditional ***strengthening/ repair techniques*** and finally showing the more sophisticated systems and techniques, particularly **F**iber **R**einforced **P**olymers ***"FRP"*** and **H**igh **P**erformance **C**oncrete **"*HPC*"** , now being extensively introduced in Jordanian rehabilitation practices amongst which some can be adapted to accommodate ***preservation*** requirements for ***historical*** and ***ancient*** buildings as well.

Keywords; Assessment; Repair; Strengthening; Retrofit; FRP; HPC

1. Introduction

Many reinforced concrete and masonry buildings in Jordan, like other countries, are getting old which is often accompanied by sever condition degradation due to several structural and/or environmental factors and hence they need rehabilitation.

Structural assessment can be initiated, when there has been a change in resistance, such as structural deterioration due to time-depending processes (e.g. corrosion and fatigue - spalling, cracking, and degraded surface conditions are typical indications of deterioration**)** or structural damage by accidental actions or fires. Also when there will be a change in loading (e.g. the need to support additional floor/ floors or changes of use/ function) or an extension of the design working life.

Assessment can also be carried out to analyze the current structural reliability (e.g. for environmental hazards like earthquake or extreme winds).Sometimes, it may be necessary to assess an existing structure after concerns about the correct design and construction arise, including low quality building material or workmanship.

2. Rehabilitation

Rehabilitation can be defined as an operation to bring a structure or structural members to specified safety and performance level, depending on the state of the structure or structural members, rehabilitation can be divided into two categories: ***repair and strengthening.***

Repair is the rehabilitation or attempt of restoring strength and/or stiffness of a damaged/ deteriorated structure or a structural member, whereas ***strengthening*** is upgrading or increasing strength and/or stiffness of an undamaged/ original structure or member.

In practice repair/strengthening interventions in many cases are introduced while the structural member is still under load, and sometimes after unloading the member by jacking.

Furthermore, changes and update of National Building Codes including provisions for earthquake resistant design necessitate ***upgrading*** or ***retrofitting*** of unqualified structures, especially buildings constructed of un-reinforced masonry which represent a significant risk during an earthquake.

3. Assessment Process

3.1 *Objectives*

The first step of the assessment process must always be **the clear specification of the assessment objective**. This is essential to identify the most significant limit states associated with the structural variables to be investigated and with those the assessment procedure to be applied.

There are **two main objectives** to conduct assessment of existing structures, **the assurance of structural safety and serviceability** and the **minimization of costs**.

3.2 *Classification*

A wide range of different assessment procedures exists with varying complexity/ levels, starting with simple but conservative methods and progressing to more refined but also more expensive methods. Therefore, the choice of the appropriate procedure depends highly on the specified requirements of assessment.

In general assessment procedures can be classified into three groups: ***measurement based*** assessment, ***model based*** assessment and ***non-formal*** assessment.

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1- Measurement Based Serviceability Assessment :

Assessment of serviceability (load effect) by measurement of performance values and comparison with threshold values. There is no structural analysis carried out. The threshold values can be given in codes or individually specified.

Measurement based assessment routines are in general not complex. An example application is the evaluation of serviceability measures like displacement (e.g. mid-span deflection) – load tests or dynamic behavior and properties like natural frequencies and mode shapes of the real structure.

2- Model Based Safety and Serviceability Assessment :

In this category the load effects are determined by model based structural analysis. Using this method Ultimate Limit State and Serviceability State can be modeled and therefore assessed.

Most assessment applications are processed based on a structural model; including the following levels:

Level 1: Based on document review:

Assessment of safety and serviceability using simple model based methods. Data from documents.

Level 2: Based on supplementary investigation:

Assessment of safety and serviceability using refined model based. Data from tests, monitoring, etc.

Level 3: Modified target reliability:

Adaptation of target reliability measures and assessment of safety and serviceability with modified structure specific values.

Level 4: Full probabilistic assessment:

Probabilistic assessment of safety and serviceability values, Data from tests, monitoring, etc.

3- Non-Formal Assessment :

In this category assessment routines are based on the experience and the judgment of the assessing engineer, where the structural condition is evaluated on the base of visual inspections. For example, the engineer is able to evaluate visual deterioration effects like corrosion of steel members or visual signs of damage (cracks, spalling). These assessment routines are more or less subjective and are applied only exceptional.

3.3 Methodology

Stage 1

Gathering of information, documents, specifications, properties and drawings related to the structure understudy, as well as, information about the previous, current and/or future loading on the structure.

To assure that the reviewed documents are correct **a verification procedure is to be conducted** whenever possible. For example, obtained architectural (geometric) and structural details can be easily checked or verified on site using ordinary or laser meters, chiseling or chipping tools, cover-meters, survey instruments, electronic gauges, etc. , ***Fig(1)***.

Fig.(1)

A survey of the existing condition of the structure is the first step in its evaluation process. During this stage deteriorations and distresses are observed **(visual examination)**, which may require further **in depth examination** or **special inspections** for detection and investigation of deterioration processes like corrosion and fatigue/ cracks [***Fig.(2)***] and for detection of changes in the structural systems. Time depending processes like deterioration or cracks movements sometimes need to be acquired.

Fig.(2)

A thorough materials and structural review may give dues to the cause of distress or the deterioration observed. **Environmental conditions** are of **physical, chemical or biological** nature and can have an effect on material properties.

Stage 2

Testing and evaluation of materials properties used in the construction. The tests can be destructive and non destructive. They can be conducted on site or at a laboratory.

During this stage the examining team should consider the optimum ways of getting the information needed without destroying or damaging the construction with respect to its historic or artistic characteristics.

Several **nondestructive tests** may be made of various parts of a construction in place. For example, **Rebound (or Schmidt) Hammer** ***(RH)*** [***Fig.(3)***], and **Ultrasonic Pulse Velocity (or** ***UPV*****)** method [***Fig.(4)***], are very useful field tools for testing hardened concrete.

Nondestructive tests (Particularly, ***RH & UPV***) should also be combined with a sufficient number of destructive tests to determine the strength parameters of the used building materials.

Fig (3)

Fig (4)

Radiographic / Ultrasonic / Magnetic Particle Examinations, and Liquid Penetrate Inspection (also called **Dye Penetrate Test**) are used for **testing structural steel** members in addition to their connecting bolts and welding [***Fig.(5)***]. Nondestructive **coating/paint thickness measurement** on structural steel members is carried out utilizing the ***Portable Deltascope Gauge, Fig (6).***

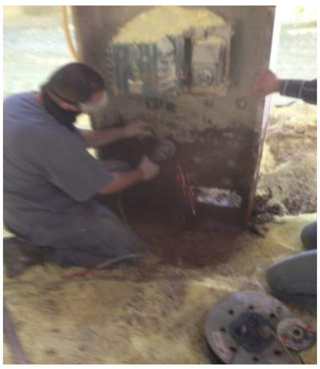

Fig (5)

Fig (6)

An example of **destructive testing** is concrete **core test** [***Fig. (7)***] and reinforcement **tensile test**, or alternatively, utilizing **pull-out or pull-off field tests**. Also **Uniaxial Tensile "*Pull*" Test** is used for structural steel.

Fig.(7)

In most cases, **foundations and sub-structural exploration**, as well as, **geotechnical investigations** are required***, Fig (8).***

Fig.(8)

Chemical examinations may also be required (e.g. **carbonation and chloride/sulphate content of concrete**)***, Fig (9).***

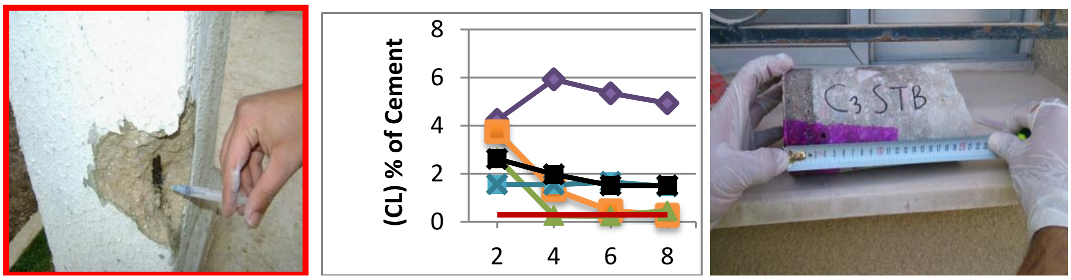

Fig.(9)

Stage 3

Based on the results of the two above stages, the safe service load carrying capacity of the structure, or **structural adequacy, should be investigated** by performing full or partial structural analysis. The analytical **model** should reflect or represent the **actual condition and loading** of the existing structure.

For **lower assessment levels** it is often effective to calculate load effects with basic conservative methods with **simple structural models** [***Fig. (10)***]; provided that the approximately large uncertainty is regarded with an adequate safety measure. For **higher assessment levels** refined methods can be implemented including **finite element analysis** and **non-linear model**s**,** ***Fig (11).***

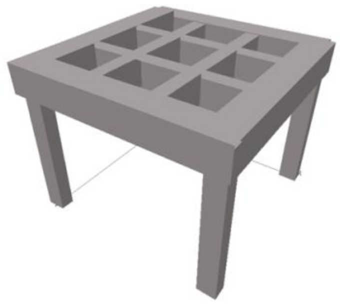

Fig (10)

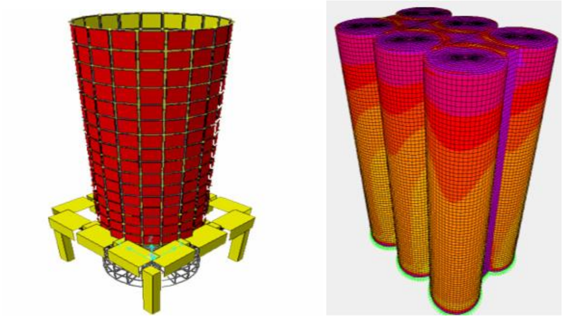

Fig (11)

In cases where the analytical method is impractical or otherwise unsatisfactory, a **static load test** may be recommended as **an alternative method for structural evaluation**, ***Fig (12).***

Fig (12)

Determination of damage and its extend and decisions regarding the **need for structural rehabilitation**, including seismic upgrading, are arrived at after the completion of the analytical stage.

Finally, a **full technical report** including inspection procedures laboratory examination and analysis results, conclusion and recommendations shall be prepared and illustrated with appropriate documentation (photographs, tables, plans, etc.).

Stage 4

Based on the above, **appropriate systems and techniques** for all **necessary changes or repairs are made** to make the structure adequate for the rated capacity. A **repair program** is formulated based on experience (previous repairs for similar projects), and **a qualified restoration contractor** is selected for work execution.

While the work is underway, a qualitative approach for Quality Assurance/Quality Control **(QA/QC)** is to be implemented, including close monitoring of equipment and structure/site conditions. Upon completion of the repairs, a follow up evaluation is often conducted by a consulting agency.

4. Current Rehabilitation Practices in Jordan

4.1 Traditional Strengthening Techniques

The **current rehabilitation practices in Jordan** are mainly concerned with **post-intervention** behavior and strength of structural members and systems. Some traditional/ classic strengthening techniques will be briefly discussed in the following paragraphs.

Column Jacketing

Is a technique widely used for strengthening concrete columns. Column cross section is enlarged by formulating a jacket around the existing column, and additional longitudinal and transverse reinforcement is provided [***Fig. (13)***]. Steel plates encasement or caging is also used for column strengthening/ confinement, ***Fig (14).***

Fig (13)

Fig (14)

Adding New RC Section

A common method for strengthening of reinforced concrete beams is casting a new concrete layer/section with new longitudinal reinforcement after chipping the concrete cover, ***Fig (15).***

Fig (15)

Strengthening with Adhesive Bonded Steel Plates

Another method for beam strengthening is the use of epoxy glued steel plates***, Fig (16).***

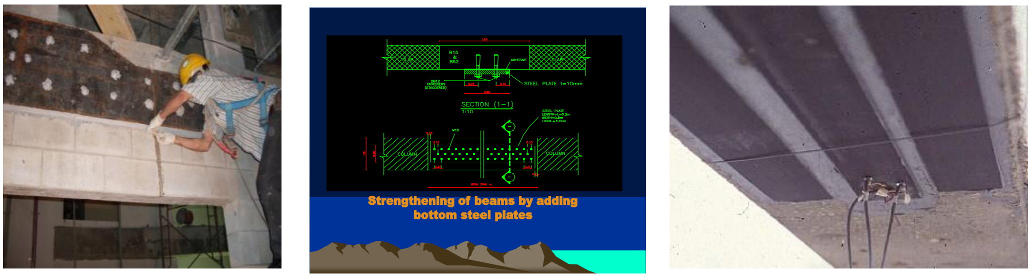

Fig.(16)

Slab Overlay / Underlay

Casting a new reinforced concrete layer over/under the existing slab is the most commonly used method for strengthening of reinforced concrete slabs***, Fig (17).***

Fig (17)

Incorporating New Elements

Examples: adding steel beams/ frames for slab strengthening and introduction of shear walls to improve seismic resistance of buildings***, Fig (18).***

Fig.(18)

Foundations Enlargement - Underpinning

Dimensions' **enlargement** technique [***Fig. (19)***] is used where foundations need to be **strengthened** to take an increased load, for example, if extra stories are to be added**,** while **underpinning techniques** [***Fig. (20)***] are used to support buildings/ structures with their foundations suffering subsidence problem (failure of foundations due to extensive or uneven subsidence of underneath soil).

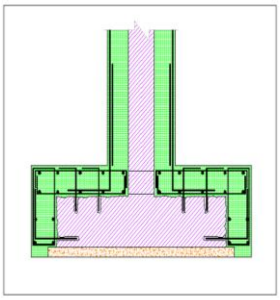

Fig (19)

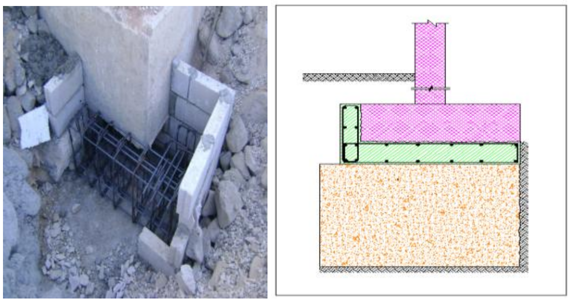

Fig (20)

4.2 Use of FRP Composites

The **use of (*FRP*)** composites as a substitute to steel plates and in other strengthening techniques is **being increasingly introduced to the current Jordanian rehabilitation practices**. Yet, their use as an alternative material to the traditional steel reinforcement in civil work has not been seriously adopted.

FRP composites emerged as a promising solution to many structural problems associated with aggressive environments to steel, or when special demands are placed on reinforcement, such as, **high strength-low weight or non-metallic characteristics**.

An example on the benefits of ***FRP*** composites is their use as **a substitute to epoxy bonded steel plates in tension faces** of structural members. Steel plates are heavy [***Fig. (21)***] and need to be connected to the member during the application. Moreover, steel plates are prone to corrode, especially near the steel/epoxy interface. On the other hand, ***FRP*** laminates can be easily put and glued in place without any external support, [***Fig. (22)***] accompanied with their high ability to resist corrosion.

Fig (21)

Fig (22)

Another example on the benefits of ***FRP*** composites is their successful **use for seismic upgrading of reinforced concrete columns, walls and joints, *Fig (23).***

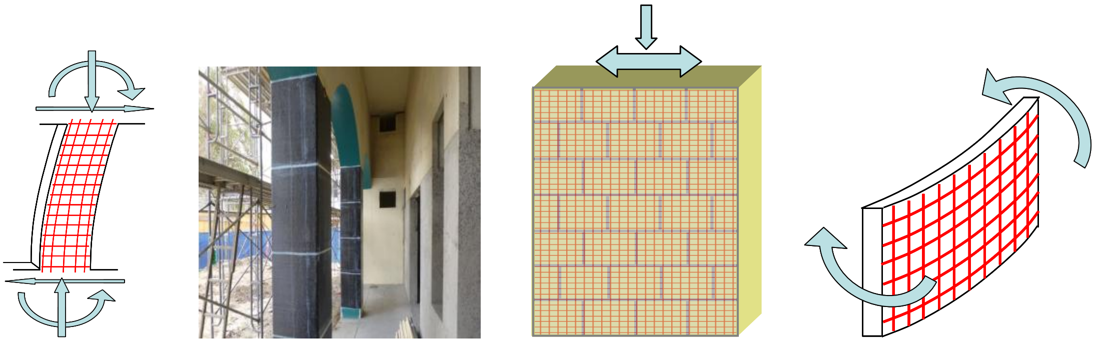

Fig.(23)

4.3 High Performance Concrete – HPC

In normal conditions "conventional" reinforced concrete is usually used for strengthening R.C buildings and structures, however, execution of particular applications or in some complicated situations such as difficult access/ placemen, or complex shapes and congested reinforcement, concreting becomes very difficult and even impossible without losing concrete's homogeneity - stability or consistency (no segregation).

In other applications special specifications for concrete may be required: both in its fresh state; like high workability – self placing, or its hardened state; like outstanding mechanical properties which may further need to be compatible/ close to those of the substrate, or where low permeability – high durability is required, for example, in harsh conditions or severe environment, and last but not least, where early improved resistance is requested for speed construction.

ACI Definition

- **H**igh **P**erformance **C**oncrete **"*HPC*"** is defined as a concrete meeting special combination of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing, and curing practices.

New Definition

- ***HPC*** is a concrete that has been designed to be more durable and if necessary, stronger than conventional concrete.
- ***HPC*** mixtures are essentially composed of the same materials as conventional concrete mixtures but the proportions are designed or engineered to provide the strength and durability needed for the structural and environmental requirements of the project.

Therefore, the use of ***HPC*** is indispensable to fulfill the overall exceptional concrete properties needed for new construction as well as for rehabilitation of existing structures [***Fig. (24)***] with improved structural response/ performance to meet safety requirements including retrofitting to resist earthquake action in active seismic areas.

Fig.(24)

In Jordan ***HPC*** is now being extensively introduced in rehabilitation practices, particularly to substitute the traditional techniques/ concrete for narrow column/beam jacketing with congested reinforcement and thin - high bond slab overlay/ underlay***, Fig (25).***

Fig.(25)

4.4 Rehabilitation of Historic Buildings and Cultural Heritage

Jordan is rich in its antiquities and archaeological sites that are spread all over the country [***Fig. (26)***]. Many sites date back not only to Neolithic and Chalcolithic periods, but also extend into Classical, Islamic, and even to the 19th and 20th centuries. The cultural heritage incorporates religious, residential and public buildings, in addition to cultural landscapes encompassing historic cities and villages, streets, alleys and neighborhoods.

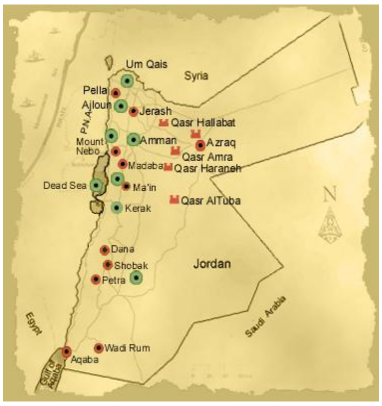

Fig.(26)

Historic buildings and cultural heritage in Jordan, like in other countries, are vulnerable to a variety of natural and human hazards, such as, weathering and aging processes, seismic hazard, functional misuse, and lack of maintenance. However, much effort has been done to preserve and protect several Jordanian historic buildings. Yet, the traditional rehabilitation techniques should be improved. New preservation technologies and seismic upgrading strategies should be developed. The new technologies should be "reversible", and visually compatible with historic building to the greatest extent.

In this regard, and as part of "***OPERHA"*** international research project (completed on November, 2010) on the rehabilitation of ancient and heritage buildings using innovative "***FRP***" composite system - developed in collaboration with some leading research **Mediterranean** and **European** parties, the Royal Scientific Society (***RSS***) and the Department of Antiquities (***DOA***) have selected one of the most famous early Islamic monuments of Jordan "**Qasr Al-Haraneh**" [***Fig. (27)***] as a "**Case Study**" to ascertain the validation of the "new" ***FRP*** product designed and developed by ***OPERHA*** parties for structural strengthening of historical buildings.

Fig.(27)

The Project revealed that ***FRP*** composites can be adapted to accommodate preservation requirements for historical and ancient buildings. Their superior properties, reversibility, and low visual impact make them a very attractive choice in solving most of historic or ancient buildings' problems***, Fig (28).***

Fig.(28)

4.5 Seismic Assessment and Retrofitting

Jordan is considered as an area of moderate seismic hazard [***Fig. (29)***]. The last major earthquake was the "***1995 Aqaba Earthquake*** "with a magnitude of (***6.3)*** on the (***Richter)*** scale. Since that time, the government's communities and professional engineers in ***Jordan*** have become much more aware of seismic hazard. Moreover, they have recently decided to carry on with task of writing a new and improved seismic code, with the assistance of the ***Royal Scientific Society,*** taking in account the latest seismic provisions, theories & methods.

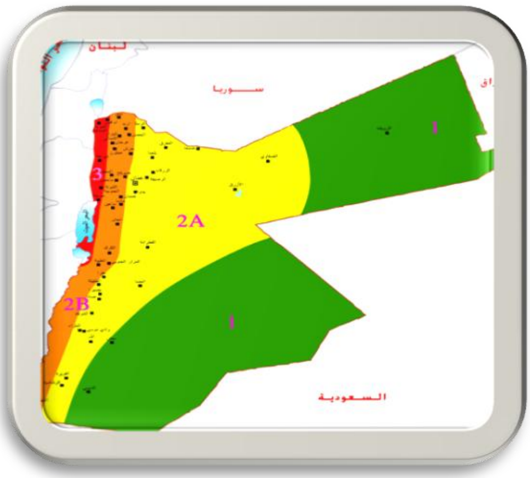

Fig.(29)

Additionally, world class engineering standards and practices became very imminent to improve the quality of engineering designs and risk assessment of existing structures in ***Jordan***. This demanded setting up seismic risk assessment and rehabilitation training courses, national and international workshops and conferences which would enhance the engineer's knowledge in the new seismic provisions.

One recent example of these conferences and workshops was the four-module specialized "222 hour - one and a half year" training program on ***"Seismic Analysis, Assessment and Retrofitting for R.C Structures using Computer Aided Design " CAD' "*** **,** issued in Amman; Jordan on November, 2014.

The program was sponsored and supervised by the National Building Council (***JNBC-MBWH***), managed and funded by The United Nations Development Program in Jordan (***UNDP - Jordan***) and organized and conducted by the Royal Scientific Society (***RSS***).
Two international teams of experts from esteemed consulting firms in ***Italy*** and ***Turkey*** were employed to execute the program.

23 Jordanian structural engineers were carefully handpicked from various public and private sectors to participate in the training program which was held in a well equipped hall [***Fig. (30)***] at **Princess Sumayya University for Technology (*PSUT*).** Successfully graduated participants were intended to become future trainers for more engineers, utilizing the pyramid method to disseminate knowledge.

Fig.(30)

The program was presented in four successive packages during the period (3^{rd} of March, 2013 to 4^{th} of September, 2014), **started with extensive theoretical sessions** accompanied by several applications – selected previous case studies**.**

Nonlinear dynamic procedures and methods [***Fig. (31)***] utilizing two state of the art software packages (***SeismoStruct/Italy*** & ***STA4CAD/Turkey***) were adopted while performing the analysis. Exams were also given to participants to test the amount of knowledge gained during this stage.

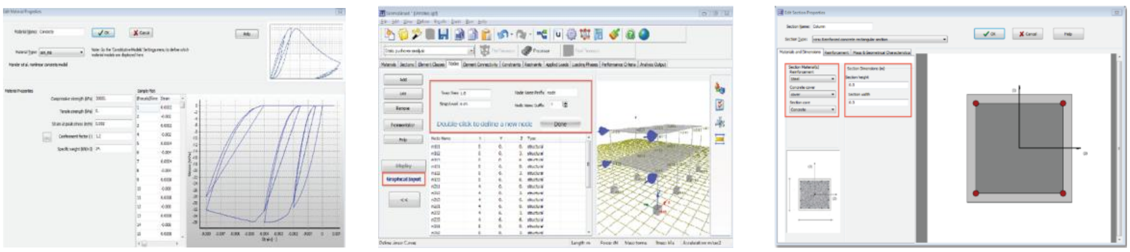

Fig.(31)

Upon the completion of the theoretical part, **a number of case studies of actual vital existing buildings in Jordan** (about 15) **were distributed** amongst the participants/groups where they used and applied the knowledge acquired from the training **to analyze, assess and suggest / verify recommendations for seismic retrofitting,** ***Fig (32).***

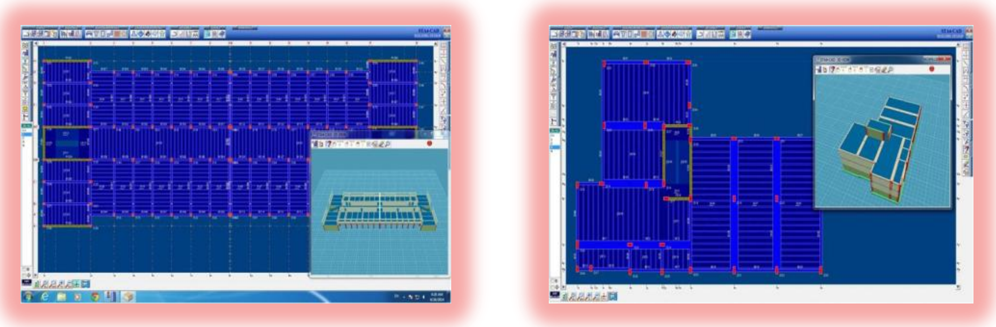

Fig.(32)

4.6 Need for National "Assessment " Code

Structural codes have been developed **for new design**, but they often **are not appropriate for assessment** since there are significant differences between design and assessment. The main difference is that in the latter **uncertainties can be reduced significantly** by site specific data from the real structure.

Design uncertainties arise from the prediction of load and resistance parameters of a new structure. These uncertainties represent the variability of a large population of structures caused by the unequal qualities of material, the different construction practices, and the variability of site specific live loads. Also a conservative design does not result in a significant increase in structural cost while a conservative assessment may result in unnecessary and costly repairs or replacement.

Therefore, **there is a clear need for technical rules for the assessment of existing structures in Jordan**. In some countries, especially the ***UK***, assessment codes and guidelines are available, but in most European countries only single assessment routines are discussed within the scientific community, but are rarely applied by practicing engineers.

5. Assessment Vs. Forensic Engineering

5.1 What is Forensic Engineering ?

Forensic engineering is defined by the National Academy of Forensic Engineers (***NAFE***) as **"the application of the art and science of engineering in matters which are in, or may possibly relate to, the jurisprudence system, inclusive of alternative dispute resolution."** These engineers serve as consultants to the legal profession and as expert witnesses in courts of law.

- Forensic engineering is **the application of engineering principles to the investigation of failures or other performance problems**. Forensic engineering also **involves testimony on the findings of these investigations before a court of law or other judicial forum**, when required.

5.2 Why Forensic Engineering ?

With rapid economic development, increased design sophistication, more-and-more daring construction technology and accelerated project delivery came the proliferation of structural failures throughout the world. Several countries are reviewing and/or streamlining technical, business, and legal procedures modeled on their practices - which require expert consultants/ witnesses in both the forensic investigation and in the ensuing dispute resolution.

5.3 *Forensic " Structural " Engineering*

Engineering investigation and **determination of the causes of structural failures of buildings** [***Figs. (33&34)***]**, bridges and other constructed facilities**, as well as, rendering opinions and **giving testimony in judicial proceedings**.

Fig.(33)

Fig.(34)

5.4 *What Encompass A Forensic Engineer ?*

An engineer's **success** in the field of **forensic engineering** is the result of the **combination of many components** in his or her background: first, a good education in engineering and its related subjects; then years of hands-on experience in analysis, design, construction, testing, inspection, condition assessment, and trouble-shooting; understanding of the design-construction process; ***comprehension of legal implications***; good communication skills; a knack for problem solving; a positive attitude to team work; a strong sense of ethics; self-confidence without arrogance; confident and credible disposition; and a high level of intellectual sophistication. **Some** of these traits **can be learned but some are ingrained or acquired.**

5.5 Assessment Engineer Qualifications

Except for the legal implications/ requirements, but still an advantage, almost all abovementioned **components/ qualifications needed for making a successful "*Forensic Engineer"* are also essential for creating a professional "*Assessment Engineer"***, maybe with additional /specific technical and field skills, as can be inferred from the below ***performance form*** used for assessing and developing ***"Assessment and Rehabilitation of Existing Structures Unit "*** staff at the ***"Engineering Consultations Division - CSBC "*** of the ***"Royal Scientific Society - RSS".***

RSS Competency Form – Staff Performance Evaluation - Assessment&Rehabilitation Unit

Component		Assessment Engineer Qualifications
Academic/ Technical skills		Education; Structural Analysis; Design & Codes: R.C Buildings, R.C R.W, Struct. Steel, Seismic; Used Structural Software; Understanding Design& Construction Process; Auto CAD Office; Internet &Search; Training Courses
Field Skills	Prelimin-ary	Information – Data Gathering: Docs.&Drwgs., Specs.& Properties, Previous Reports / Invest., Data Review; Changes Detection: Geom. Verific., Initial Analysis, Structural Verification; Work Management: Manpower & Tools, Sampling For Lab Tests, Coordination
	Condition Survey	Visual Inspect.; Structural Inspection: Substructure (T.P.S), Superstructure; Sub Soil Condition; Environmental Conditions: Physical, Chemical, Biological; In- Depth Inspections: Soundness Test, Carbon. Test, Corrosion Detection
	Specific Tasks	Loading Test; Non- Destructive Tests - NDT: Struc. Steel & Welds, Hardened Concrete; Surveying; Crack Monitoring
Reporting Skills		Offer Prep.; Struct-uring; Meth-odlog; Follow-Up: Drafting, Labs, Geotec; Results Evaluation; Assessment & Correlation; Recomm-endations; Solutions; Present-ation
Tendering Skills		Drawings & Details; Specs.; B.O.Q; Qty. Survey; Cost Estimation
Supervision Skills		Tender Interpretation; Follow Up & Inspection; FIDIC & Contract; Quality Control QA/QC; Materials Approval; Quantity Control; Schedule & Progress; Determin-ation; Project Management
Values , Ethics , & Achievements		Enthusiasm, Confidence & Tendency; Responsibility &Client Satisfaction; Potential & Development; Teamwork & Knowledge Dissemination; Communi-cation; Multitask; Completion; Effective Time /Effort; Productivity

Rating	Excellent / Exceptional (5)	Above Average / Exceeds Expectations (4)	, Average / Meets Expectations (3)	Below Average / Improvement Needed (2)	Poor / Unsatisfactory (1)	Too New to Rate (0)

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