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# Comments on Quality Assurance drawn from Building Collapses

## Commentaires sur l'assurance de la qualité basés sur l'écroulement de bâtiments

## Bemerkungen zur Qualitätssicherung anhand von Bauwerks-Einstürzen

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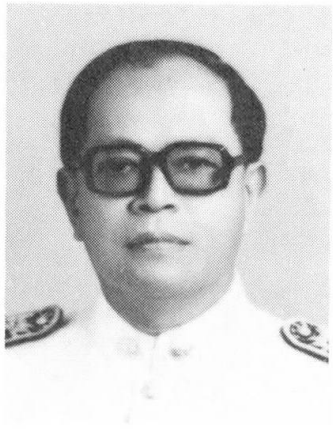

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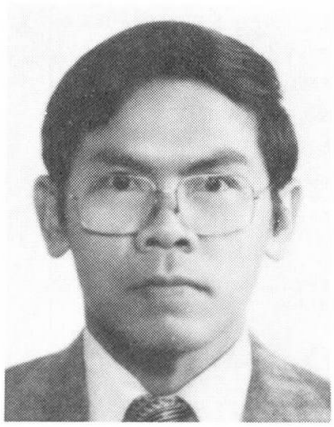

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**SUMMARY**

Structural performance in strength and serviceability can be guaranteed only when quality assurance measures have been implemented by the process of analysis, design, construction, operation and maintenance. Some comments were drawn from several cases of collapse in Thailand where structural investigation had been conducted to find major causes of failure. Quality assurance can be improved by means of analysis, experience and control by engineers, contractors, inspectors and owners upon their responsibility.

**RÉSUMÉ**

La durabilité et la serviciabilité ne peuvent être garanties que sur la base de mesures appropriées d'assurance de la qualité, lors de l'étude du projet, de sa construction, de son exploitation et de son entretien. Plusieurs bâtiments se sont écroulés en Thailande et des études ont été entreprises pour déterminer les causes majeures de ces accidents de structures. L'assurance de la qualité peut être améliorée par l'application et le contrôle de règles et procédés par l'ingénieur, l'entrepreneur, l'inspecteur et le propriétaire.

**ZUSAMMENFASSUNG**

Tragsicherheit und Gebrauchstauglichkeit von Bauwerken können nur gewährleistet werden durch Massnahmen der Qualitätssicherung im ganzen Prozess von Berechung und Bemessung, Erstellung, Nutzung und Instandhaltung von Bauwerken. Die Untersuchung verschiedener Bauwerks-Einstürze in Thailand gibt Anlass zu einigen Bemerkungen über Qualitätssicherung, die durch Ingenieure, Unternehmer, Kontrollinstanzen und Eigentümer in ihrem jeweiligen Verantwortungsbereich verbessert werden kann.

## 1. INTRODUCTION

Many buildings collapsed or defected and needed repair due to structural failure. Quality assurance of the structures will lead to excellent performance in strength and serviceability, in short terms and long terms. Sound structures can be obtained only when quality assurance measures have been implemented along the process of analysis, design, construction, operation and maintenance. Comments drawn in this paper are from various structural investigation of collapse cases in Thailand. The investigation was conducted mostly after the collapse had taken place partially or completely. The investigation is to figure out the causes of structural failure by means of physical observation, and analytical solution. Most common causes of damage for sub-structures and super-structures are illustrated corresponding to the failure cases.

Some comments on quality assurance are drawn from cases where causes of failure are identified. The comments are critic on academics, practices and regulation through engineers, contractors, inspectors and owners. The very nature of progress itself requires the excercise of control, whenever the quality assurance is lack, then it could result in problems and lead to collapse.

## 2. STRUCTURAL INVESTIGATION

The investigation of structural failure especially after its collapse is quite complicated. Methods and procedures may vary by cases due to severity of the collapse, left over symtoms, available information and its mode of failure. The major task of the investigation is to find out primary causes of failure. In some cases, secondary and tertiory causes may be also found.

The process will concern data collection, physical examination, structural analysis and loaded tests. The data collection and physical examination must be done first, then several possible alternatives are assumed and the actual causes can be confirmed by means of analyses and tests.

## 3. MOST COMMON CAUSES OF FAILURE

From various cases of structural investigation of building collapse, several causes can be grouped for sub-structures and super-structures as shown in Fig. 1 and 2, respectively.

For sub-structures, most common causes of failure are due to insufficient soil data, soil subsidence, differential settlement, off-center pile, excavation, slope stability and soil distrubance.

Collapse cases in super-structures are primarily concerned with un-equilibrium of forces, reliability of computer software, insufficient structural detailing, formwork failure, over loads during construction, poor control of material quality, tolerance and workmanship, misuse of the structures, and un-foreseen problems.

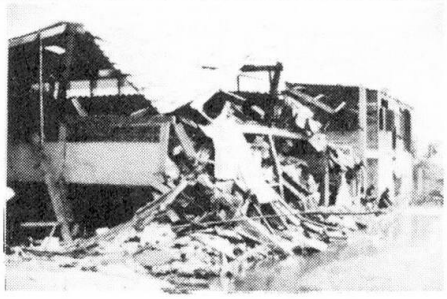
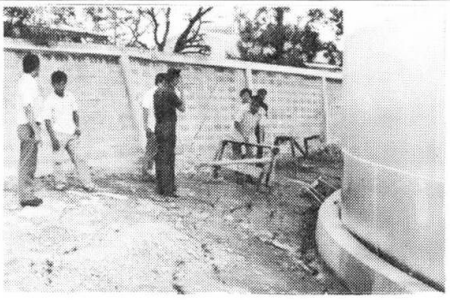
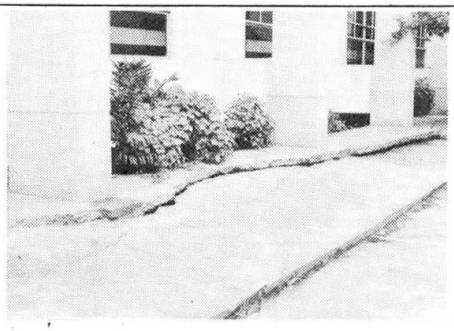
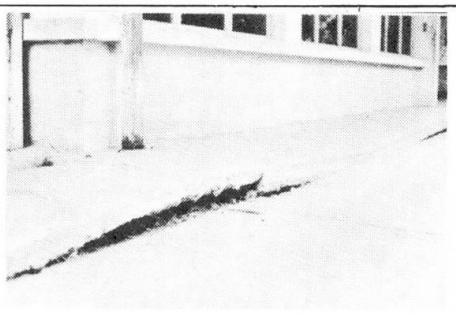
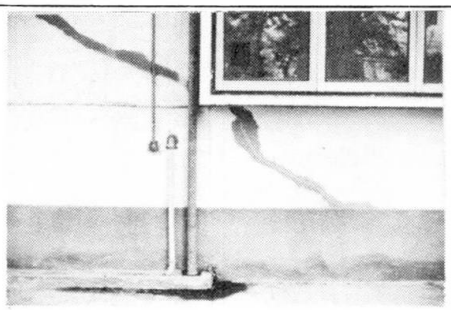
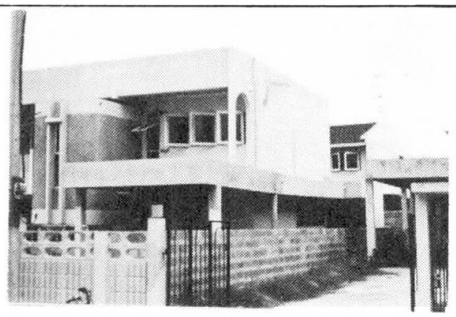
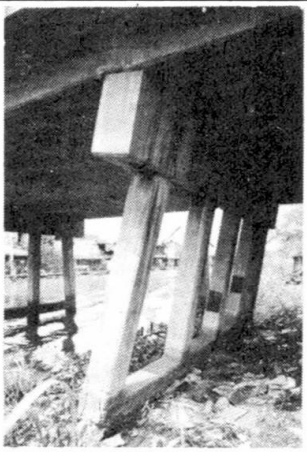
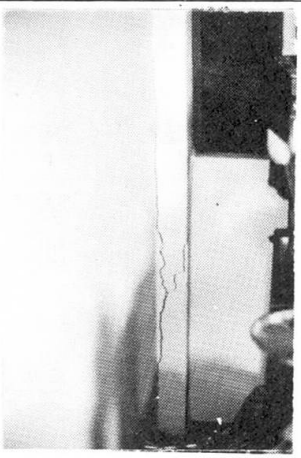
| Cause of failure | Example of failure cases | |
|---|---|---|
| Insufficient soil data |  No soil investigation |  Mis-interpretation of soil data |
| Ground subsidence |  Collapse at building edge |  Wave form up hold on on the foundation |
| Differential settlement |  Different pile length |  Different loads |
| Off-center piling |  Effect on column |  Effect on wall |

Fig. 1 Collapse cases of sub-structures

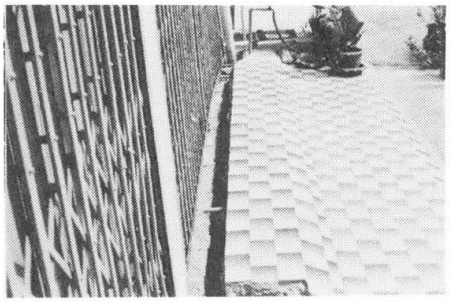
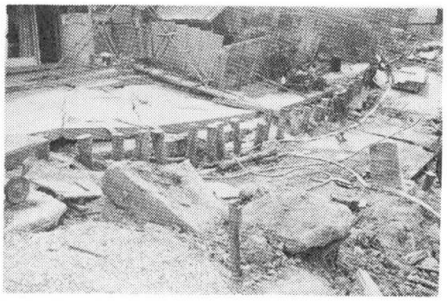
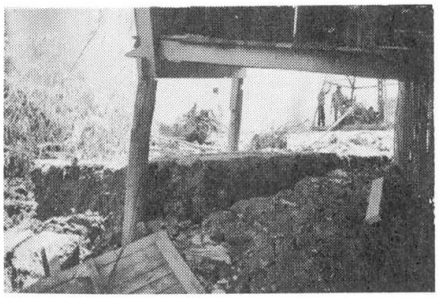
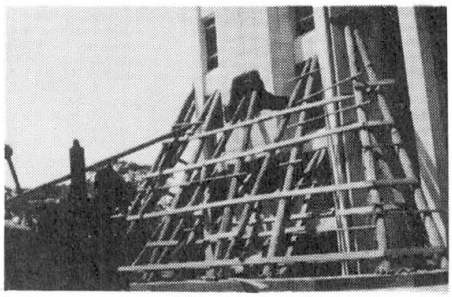
| Cause of failure | Example of failure cases | |
|---|---|---|
| Excavation |  Movement due to excavation |  Slope failure due to excavation |
| Slope Stability |  | Fail of slope |
| Soil disturbance |  Disturbed from water table |  Disturbed from equipment |

Fig. 1 (Cont.) Collapse cases of sub-structures

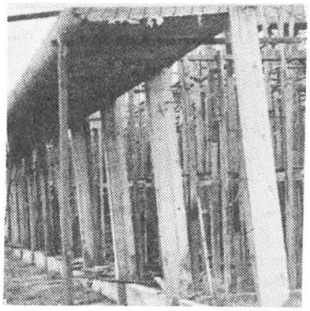
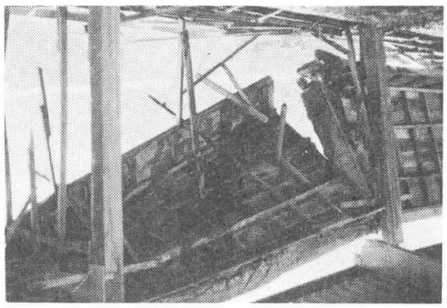
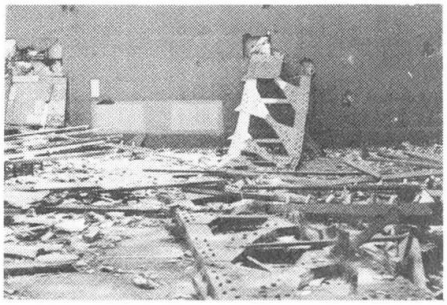
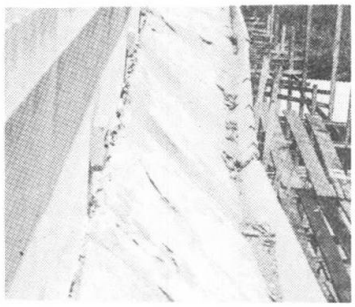
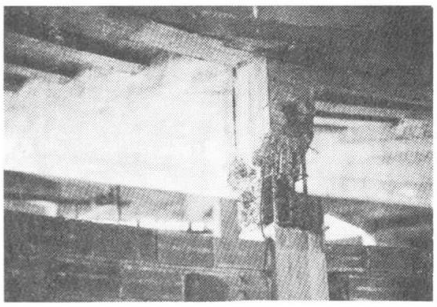
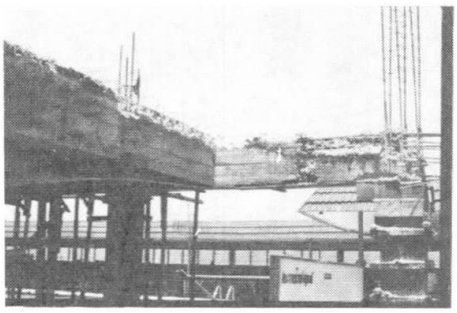
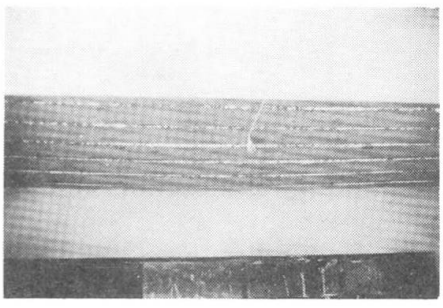
| Cause of failure | Example of collapse cases | |
|---|---|---|
| Un-equilibrium of forces |  Contilevered slab at intermediate floor |  Summation of moments is not-zero |
| Reliability of computer program |  No stability checking | |
| Insufficient of structural details |  Rebar at bottom for cantilevered slab |  Beam/column joint |
| Formwork failure |  Collapse during pouring |  Excessive deformation |

Fig. 2 Collapse case of super-structures

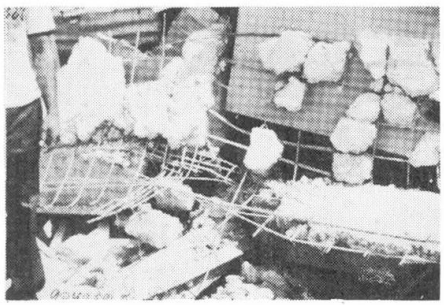
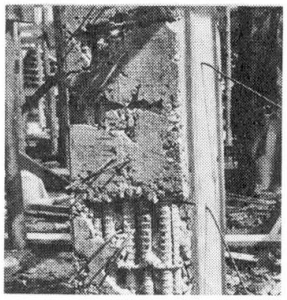
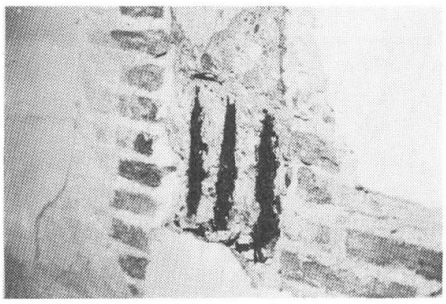
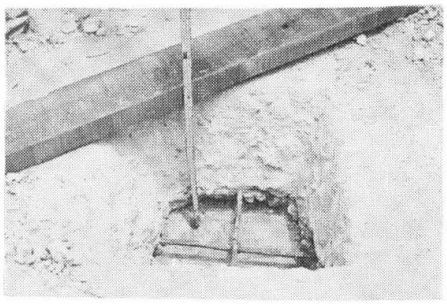
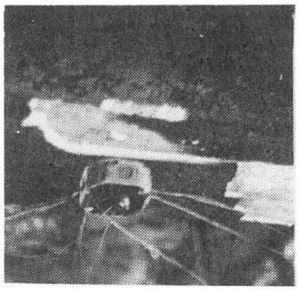
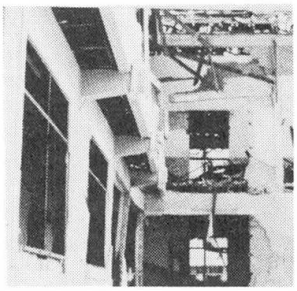
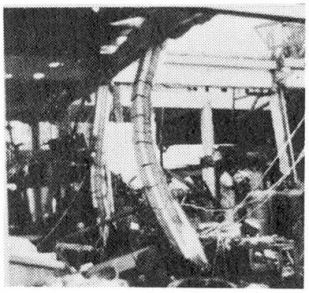
| Cause of failure | Example of collapse cases | |
|---|---|---|
| Poor centrol of materials |  Low strength concrete |  Honeycomb |
| Workmanship and it tolerance |  Less covering |  Slab is thicker than requirement |
| Mis-use of the structures |  Over-loaded uses | |
| Un-foreseen problem |  Fire |  Bomb  Gas explosion |

Fig. 2 (Cont.) Collapse case of super-structures

Such causes of failure can occur not only during the phases of design, and construction but also during operation and maintenance. Various parties such as engineers, architects contractors, owners and users are always involved.

## 4. COMMENTS ON QUALITY ASSURANCE

According to various causes of damages as illustrated in this paper, several measures of quality assurance must be implemented at all stages of project development as the critical comments below:

### 4.1 By-Law

Building regulation in Thailand is covered only the urban areas, many sophisticated buildings in the rural area are not governed by the law. However, this act should be implemented for all buildings and structures, but the degree of control can be vary due to their necessity. Law should provide better relationship amoung parties involved in the structures such as owners, engineers, contractors and users. Responsibility of each party must be clarified for easy implementation

### 4.2 Codes and Standards

Revision of codes and standards should be done more frequently to up-date design information and some specific values with the progress in theoretical development, advanced technology and new materials. Design codes on the basis of probabilistic approach which loads and resistances at various limit states of structural performance are considered. Then both quality assurance and probability to failure should be in the same basis.

### 4.3 Analysis Control

Development of modern computers and software for structural analysis have been over-emphasis on their capability rather than the reliability. Each computer program for complicated analysis requires some checking to prove the reliability prior to its uses.

Idealization of the structures for analyses is very necessary to obtain most precise behavior. Simplification of analysis models must represent the real condition within the limitation of error. Equilibrium of forces at any joints or connections must be checked. Many failure cases are due to unbalanced forces at a joint since the forces are distributed to un-assigned members.

### 4.4 Design Control

Preliminary data, associated with design data, such as materials, soil exploration, and soil invesigation must be on hand prior to the design process. Structural details must be sufficient for construction work.

Each element must be equilibrium by a set of forces. Sophisticated structural responses under soil pressure, dynamic,

vibration and long term effects should be monitored to check the performance, and to collect data for further study and development.

### 4.5 Construction Control

Materials used in construction site must be fully controlled. Emphasis should be made on concrete production and fabrication. Strength evaluation must be frequently checked and adjusted. Statistic approach can offered reasonable quaility assurance for this purpose.

Economic views of formwork design and construction have overshadowed on importance of structural quality. Formwork management should fit quality assurance and rate of construction conformed to the techniques and sequences.

Construction loading must always be checked to avoid over-loads on any components. Design live loads and date of concrete casting should be recorded and used to prevent over-loading on the structures.

### 4.6 Operation and Maintenance

Live loads should be kept to the design basis. Routine checking on durability items must be implemented as general practice by in-house personal for periodic maintenance.

Monitoring for special behavior such as settlement, vibration or drifting should be commenced to determine the stuctural performance.

## 5. CONCLUSION

Several causes of building collapse summerized in this report should be similar to several places in the world. Quality assurance of the sructures can be concluded as

1. Law and regulation must provide roles for safety and quaility assurance in terms of building regulation, qualified engineers and contractors.
2. Codes and standards should be frequently modified from advanced information and technology. Probabilistic approach for loads and resistances at various state limits should be compatible with local materials and workmenships.
3. Reliability of computer software for structural analysis must be considered on the basic concepts in idealization of the structures and equilibrium.
4. In design control, all design data must include soil investigation and sufficient structural details. Structural responses should be monitored to assure the performance under soil pressure, dynamic, vibration and long term effects.
5. For quality control of materials in construction, attention must be paid on concrete construction, formwork management, and construction techniques.
6. Functions of building must be controlled by resisting strength and durability in both short term and long term serviceability.

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