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Analysis of Non-Destructive Testing of Historic Building Structures

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ABSTRACT

This paper will focus on site analysis of historic building structure in heritage area using the Non-Destructive Method. The tests were carried out on structural elements mostly before and after repair works to justify the increase in strengths after the repair works. The test will focus on structural repair, alteration works, micro piling works and minor conservation works to the godown which was in run down condition both architecturally and structurally. Using the Non-Destructive Method, several test were carried out namely Schmidt Hammer Test, Chloride Content Test, Concrete Cover Meter Survey and Concrete Carbonation Test in order to investigate the strengthening of the building structure before and after repair works.

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INTRODUCTION

The 1929 Concrete Godown is located in the middle of along stretch of godowns that span between 33 Beach Street and No. 9 Weld Quay. 7DSM PROJECTS SDN BHD was awarded the contract to carry out structural repair, alteration works, micropiling works and minor conservation works to the godown which was in run down condition both architecturally and structurally. The building is of typical reinforced concrete, probably erected between 1900 and 1930 and of rectangular shaped. Its design is believed to have followed London County Council (LCC) 1915. The design parameters would have been concrete Mix 1:2:4 with 28 day strength of 11 N/mm2. The concrete cover for slab was 13mm, beam 25mmand columns 38mm and floor loading was specified at 5kPa. The building had internal uniformity; plans were drawn for a single bay that could be multiplied many times to create a warehouse or godown of desired dimensions. After 1900, reinforced concrete became the primary structural materials as it permits a structural skeleton with wide areas between columns to be filled with windows for maximum daylight. The beam and girder construction adopted herewith features such as wide columns with flared tops (mushroom system), tapered beams, waffle slab and thin concrete plate slab. The existing godown is of monolithic reinforced concrete frame structure with 12 bays and the roof slab was constructed using a set of crossing joists (beams), with relatively small spacing and recessed in the middle of the slab. The number of joists per span was 8. The waterproofing was laid using malthoid sheet. The first floor slab were formed by precast hollow structure supported by secondary precast concrete beams, which in turn supported by primary cast insitu beams.

Overall, the slab details as follows:

Thickness	100mm thick
Concrete Tested Strength	varied from 8N/mm2 to 13N/mm2
Reinforcement	10mm dia mild steel bars with spacing 200mm centre to centre

The primary beams spans across the width of the buildings between the front and rear walls and supports the edge columns on the 1st floor.

The beam details as follows:

Size Concrete Tested Strength Reinforcement	300 ~750 x 700mm varied from 14N/mm2 to19N/mm2 10nos -10mm dia mild steel bars on top half and 14nos-10mm dia mild steel bars on bottom half

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The flared columns measuring 450mm x 600mm with 4 nos of 13mm dia mild steel bars and 50x50 angle iron were bolted from ground level to a level of 1.5m high. Typical foundation system was rectangular in shape at each grid along grid line B and C measuring 4132mm x 1800mm x 450mm thick

Concrete Tested Strength	varied from 17N/mm2 to19N/mm2
Reinforcement	Cage of 13mm dia mild steel bars
Vertical stirrup	8mm dia mild steel bars

The ground slab details as follows:

Thickness	100mm thick
Concrete Tested Strength	varied from 6N/mm2 to 13N/mm2
Reinforcement	Nil
Base	Earth with traces of terracota layered bricks

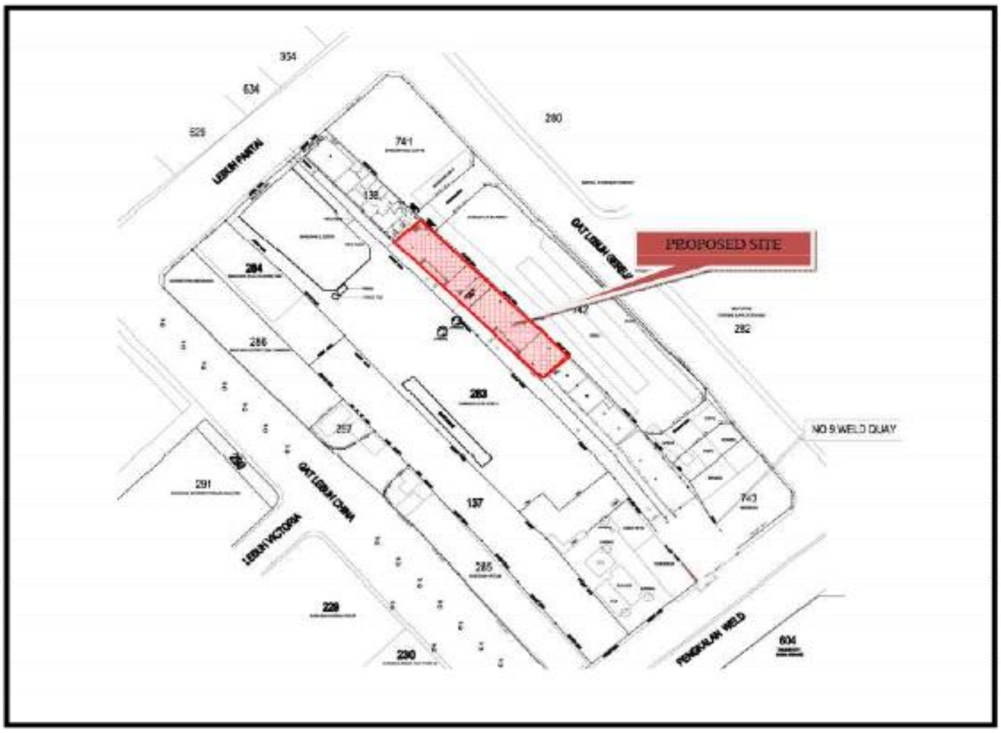


Fig. 1: Site Plan.

MATERIAL AND METHODS

Nondestructive testing or Non-destructive testing (NDT) is a wide group of analysis techniques used in science and industry to evaluate the properties of a material, component or system without causing damage (Cartz, Louis, 1995). Non-destructive testing can be applied to both old and new structures. For new structures, the principal applications are likely to be for quality control or the resolution of doubts about the quality of materials or construction. The testing of existing structures is usually related to an assessment of structural integrity or adequacy. In either case, if destructive testing alone is used, for instance, by removing cores for compression testing, the cost of coring and testing may only allow a relatively small number of tests to be carried out on a large structure which may be misleading. Non-destructive testing can be used in those situations as a preliminary to subsequent coring (Wait, J.R., 1978).

The following methods, with some typical applications, have been used for the NDT of concrete (Charles Hellier, 2001):

i. Visual inspection, which is an essential precursor to any intended non-destructive test. An experienced civil or structural engineer may be able to establish the possible cause(s) of damage to a concrete structure and hence identify which of the various NDT methods available could be most useful for any further investigation of the problem.

ii. Half-cell electrical potential method, used to detect the corrosion potential of reinforcing bars in concrete.

iii. Schmidt/rebound hammer test, used to evaluate the surface hardness of concrete.

iv. Carbonation depth measurement test, used to determine whether moisture has reached the depth of the reinforcing bars and hence corrosion may be occurring.

v. Permeability test, used to measure the flow of water through the concrete.

vi. Penetration resistance or Windsor probe test, used to measure the surface hardness and hence the strength of the surface and near surface layers of the concrete.

vii. Cover meter testing, used to measure the distance of steel reinforcing bars beneath the surface of the concrete and also possibly to measure the diameter of the reinforcing bars.

viii. Radiographic testing, used to detect voids in the concrete and the position of stressing ducts.

ix. Ultrasonic pulse velocity testing, mainly used to measure the sound velocity of the concrete and hence the compressive strength of the concrete.

x. Sonic methods using an instrumented hammer providing both sonic echo and transmission methods.

xi. Tomographic modelling, which uses the data from ultrasonic transmission tests in two or more directions to detect voids in concrete.

xii. Impact echo testing, used to detect voids, delamination and other anomalies in concrete.

xiii. Ground penetrating radar or impulse radar testing, used to detect the position of reinforcing bars or stressing ducts.

xiv. Infrared thermography, used to detect voids, delamination and other anomalies in concrete and also detect water entry points in buildings.

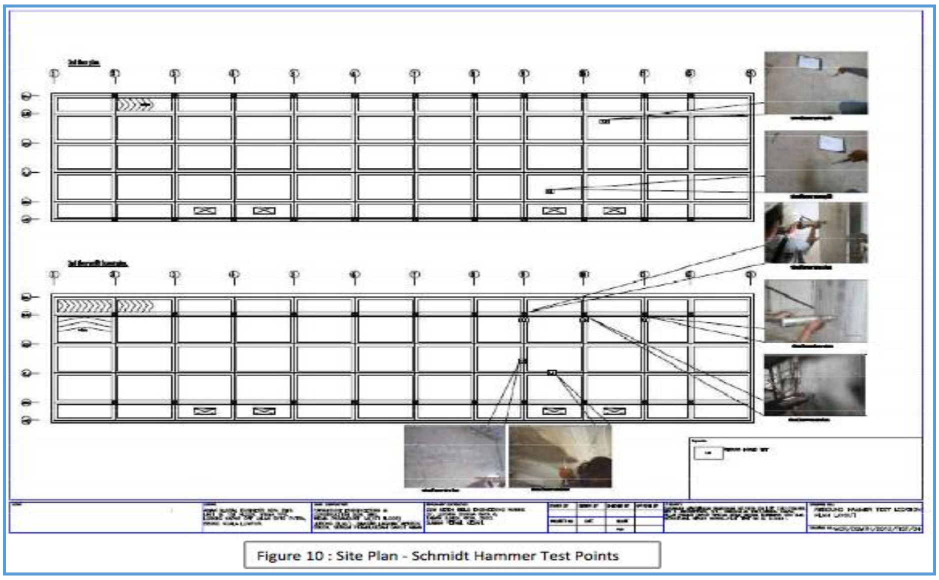


Fig. 2: Site Plan- Schmidt Hammer Test Point.

Table 1: Schmidt Rebound Hammer Test.

Test Location : Gridline 10/D - Column (1st floor)

No. of Rebound	Reading Before Repair Works (kPa)	Reading After Repair Works (kPa)
1	5.40	5.80
2	5.20	5.60
3	5.40	5.80
4	4.60	6.20
5	5.60	6.00
6	5.60	5.80
7	6.00	6.00
8	5.80	6.20
9	5.40	5.80
10	5.80	5.40
11	5.40	6.20
12	5.40	6.20
13	5.80	5.60
14	6.00	5.80
15	5.20	5.80
16	5.40	5.40
Min	4.60	5.40
Max	6.00	6.20
Mean value	5.50	5.85

Results and Findings:

The following tests were carried out on structural elements mostly before and after repair works to justify the increase in strengths after the repair works. Details as follows:

Schmidt Rebound Hammer Test (BS 1881: Part 202: 1983):

Rebound Hammer test was carried out on selected structural column, beam and slab. It serves as a tool to compare the strength of the existing concrete. It gives a good indication on the concrete surface hardness, which is reflective of the concrete surface quality and strength. The strength after repair works shows the increase rebound hammer readings.

Chloride Content Test:

Chloride when present in reinforced concrete can cause very severe corrosion of the steel reinforcement. The sources can be internal or external. In internal category, the use of seawater or other saline contaminated water are added to the concrete at the time of mixing. In external category, the structure is exposed to seawater or in the form of air-borne salt spray. The results show that that all samples extracted from the various elements of the ground floor and first floor contained acceptable content of chloride of less than 0.01% of total weight of dust sample.

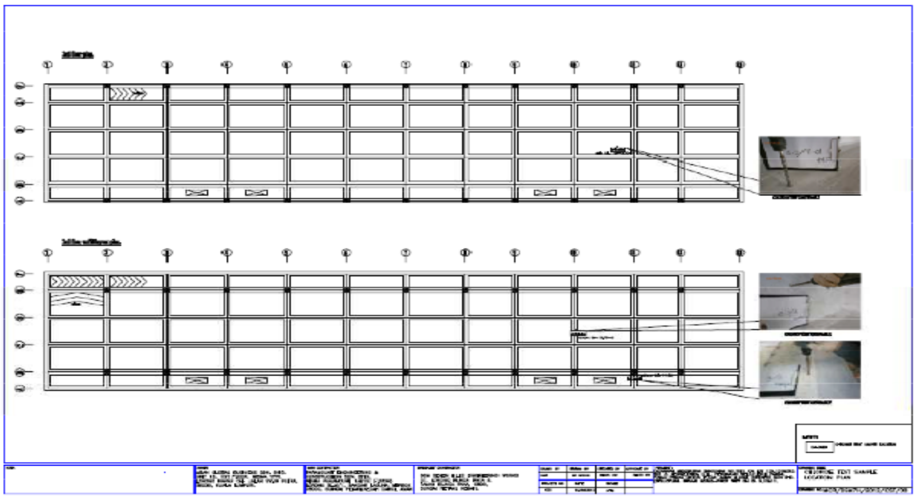


Figure 11 : Site Plan - Chloride Tested Elements

Fig. 3: Site Plan - Chloride Tested Elements.

Concrete Cover Meter Survey:

Nominal cover for structural elements are measured from concrete face to outermost reinforcement. The measured concrete cover for the structural elements showed that the structural elements satisfied the recommended concrete cover advised by LCC By Laws 1915. All repaired elements were made to pass nominal concrete cover recommended by BS 8110: 1997.

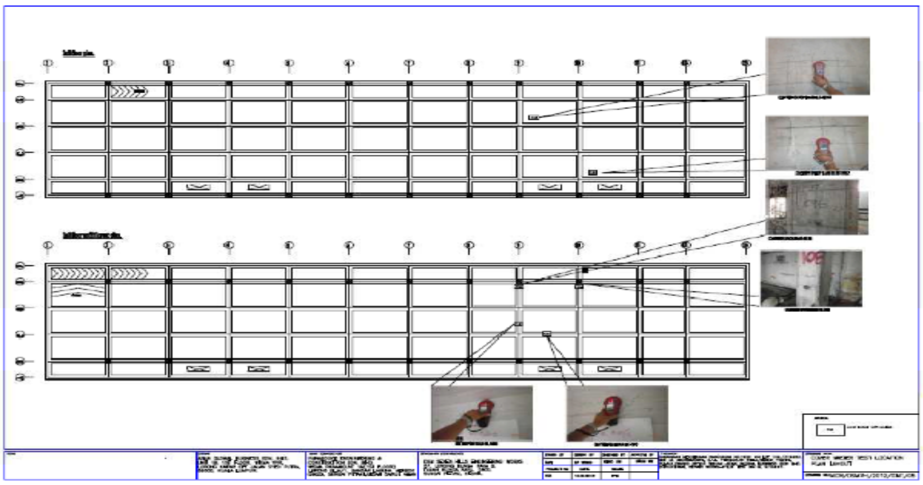
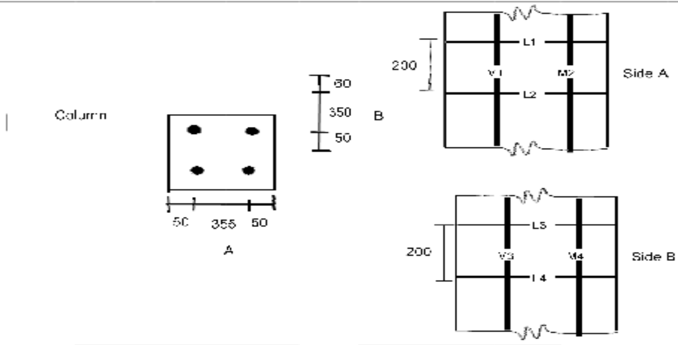


Fig 13- Site Plan - Concrete Cover Meter Points

Fig. 4: Site Plan – Concrete Covers Meter Points.

Table 2: Results of Electromagnetic Cover meter Survey on R.C members.

Results of Electromagnetic Covermeter Survey on R.C. members	
Test location/ Grid line	Position Of Rebars / Reinforcement Details
1st Floor Column 10/E	(see drawing and readings below)



Depth of cover meter reading	
Reference	Main Bar
M1	64
M2	64
M3	47
M4	69
Reference	Link Bar
L1	67
L2	65
L3	65
L4	63

Reading of bar spacing	
Reference	Main bar
S1	60
S2	350
S3	50
S4	50
S5	355
S6	50
Reference	Link Bar
S7	200
S8	200

Concrete Carbonation Test (BS 1881: Part 120: 1983):

Carbonation tests were conducted on concrete core samples immediately upon extraction BEFORE REPAIR works. The test would give an immediate measurement of the depth of the carbonation in the concrete. Carbonation occurs as a result of penetration of atmospheric carbon dioxide. In the presence of the moisture, this forms carbonic acid which neutralizes the alkality of the cement matrix. Carbonation proceeds from the surface inwards at a penetration rate depending on factors such as relative humidity and the concrete permeability. If the carbonation depth proceeds beyond the location of steel reinforcement bars, then reinforcement corrosion commences and leads to loss of structural strength.

Conclusion:

It is often necessary to test building structures after the building has hardened to determine whether the structure is suitable for its designed use. Ideally such testing should be done without damaging the building. In this papers it shows that the tests available for testing building range from the completely non-destructive, where there is no damage to the building, through those where the building surface is slightly damaged, to partially destructive tests, such as core tests and pull out and pull off tests, where the surface has to be repaired after the test. The range of properties that can be assessed using non-destructive tests and partially destructive tests is quite large and includes such fundamental parameters as density, elastic modulus and strength as well as surface hardness and surface absorption, and reinforcement location, size and distance from the surface. In some cases it is also possible to check the quality of workmanship and structural integrity by the ability to detect voids, cracking and delamination of building.

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