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ESSENTIAL FACTORS IN THE AUTOMATION OF TALL BUILDING INSPECTION

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ABSTRACT

The accumulation of the repair and maintenance requirement in Great Britain's tall housing stock has become a matter of great concern. For limited resources to be wisely allocated to this, dependable priorities based on reliable building inspection processes must be achieved. The potential role of automation has been clearly established on this. However, from survey results on current practice, it is apparent that viable automated inspection facilities (AIF's) must be able to perform a number of different inspection tasks. Furthermore, for widespread applicability, support vehicles must provide access for a range of building surface geometries. The provision of benchmarks, these formalised combinations of tasks and geometries, is an attempt to define relevant goals for worthwhile AIF research and development.

1. INTRODUCTION

This paper deals with the inspection aspects of repair and maintenance of tall buildings, and the essential factors which must be considered for worthwhile automation development. Tall buildings, of which there are more than 4400 in the England, are defined as those exceeding five storeys. The nature and extent of decay is these buildings, the inspection methods employed and the relationships between the parties employed in the industry are outlined. Whilst there is clearly scope of automation, some successes having already been achieved, their exists no clear framework for development. The provision of benchmarks, as introduced in this paper, addresses this problem, these founded on joint consideration of the inspection tasks and conditions under which they must be performed. This approach is considered to be fundamental to the extent that worthwhile developments in inspection automation are unlikely to occur without such provisions. A further area of concern is the scope of the man-machine interface (MMI) for a remotely operated automated inspection facility (AIF), which needs to be task orientated rather than purely device supportive. There is also the need to satisfy the survey data post-processing requirements for those involved in defect diagnosis, and thus move towards a fully integrated solution to tall building inspection.

2. BUILDING DECAY

The accumulation in the repair and maintenance requirement for the nations housing stock is a matter of great concern. This problem is deep rooted, for example, in 1981 the total expenditure requirement was £35 billion [1], whereas the eventual expenditure amounted to only £3.1 billion [2]. Of government owned tall buildings, there are some 27 different types of construction, these comprising insitu concrete and large panel 'system build' structures mainly constructed in the early 1960's and 1970's. In the context of inspection automation they are natural targets on account of their large number, repetition of form and difficult access requirements. Whilst accurate statistics are not available, the estimated annual repair and maintenance costs for these buildings is £357m, the inspection portion amounting to some 10% - 15%.

Many of the problems with these buildings are associated with the progressive deterioration of their concrete fabric[3], carbonation and chloride contamination being particularly deleterious. In some cases, inadequate quality control in manufacture and construction has resulted in reinforcement being too near the surface of concrete components. The combined effect of these factors is likely to be corrosion of the reinforcement, leading eventually to delamination under the expansive action of rust formation. Further defects are found in the joints between panels which may allow the ingress of rainwater. Some buildings have mosaic tile finishes or brick cladding. Both these components have associated problems, delamination in the case of tiles and corrosion of anchor ties in the case of brickwork. Deterioration of timber or metal window frames is a further problem area, and the condition of paintwork is also of importance.

An AIF for tall buildings would need to be able to gather data on a major portion of the above conditions.

3. INSPECTION PRACTICE

For successful introduction of automation, it is necessary to understand the nature of the industry, the parties involved, working relationships and the subdivision of project content. This leads to useful observations on the role of automation and who will operate it. Depending on the housing authority's capability and the size and complexity of a repair and maintenance programme, a main consultant, contractor and several sub-contractors will be involved. In the case of large projects, it is likely that specialist survey consultants will be engaged on a sub-contracted basis to the main consultant.

To achieve some clarification on this matter, the authors conducted a survey among consultants operating in the London area. This revealed a range of firm sizes, employing 0.5 to 60 persons in building survey activity, with associated annual turnovers of between £50,000 and £1,125,000. Concerning qualifications, these ranges from no formal qualifications through to graduate and postgraduate levels. On the related matter of personnel training, there are in some cases on specific provisions. Combining the findings on turnover and qualification, it is apparent that at one extreme there are inexperienced and unqualified personnel and at the other, highly experienced and qualified professionals. The existence of the former is a symptom of the aggressive market conditions where expenditure on repair is often preferred to that on fault diagnosis. It is therefore not surprising that repairs are sometimes ineffective, perhaps incurring greater expenditure in the long term. This point is reinforced in Fig. 1[4] where the cost of maintenance without inspections is seen to be higher with time, compared with maintenance associated with inspection. Furthermore, where different parties are involved in a project, responsibility and liability are almost impossible to apportion in cases of repair failure. The introduction of automation will hopefully result in greater objectivity in the inspection activity and raise its profile.

To identify the potential role of automation, it is helpful to review the consultant's approach to a project, as set out in Fig. 2[5]. Even with the most advanced form of automation it is inconceivable that this could eliminate the need for the walk over survey by a well qualified consultant. More realistically, he is best placed to estimate the extent of insitu testing, sampling, rebar determination and concrete testing. In practice, this will be conditioned by the clients budget, an unfortunate factor. Although productivity and operational economics have yet to be determined, the decision whether or not automation could be justified would depend on the volume of inspection work and factors such as difficulty of a access. In any case, it is clear that only the largest of existing firms involved in inspection work could afford to own an AIF, which is expected to cost about £30,000. What is more probable, is that specialist AIF operating contractors will emerge. A further possibility is that housing authorities with extensive tall building stock will own and operate AIFs, employing them in routine condition monitoring as well as specific repair programmes.

In the development of tall building AIFs, particular attention must be given to the likely production version costs in relation to achievable productivity. Other factors which favour automation are (a) elimination of risk to human life, (b) greater reliability of survey data, (c) automatic data logging, (d) simultaneous recording of position and probe value and (e) flexible computer based post-processing facilities.

4. INSPECTION METHODS

Table 1 sets out defect against inspection methods. With the exception of laser scanning, these are all established methods for condition assessment. Apart from with drilling and coring of concrete, the weights of probes are modest 6. Broadly speaking, there are two handling categories for probes, discrete point location and surface traversing. Referring again to Table 1, the covermeter, half cell, impulse radar and laser scanner belong to the second group, the remainder in the first. Considering the half cell, however, this can also be operated on a discrete point basis. In all cases, and with varying precision, it is necessary to set and maintain the probe orientation with respect to the surface. Contact requirements vary from proximity or light contact in the case of the covermeter and radar probes through to fixture in the case of drilling and coring. Use of the half cell, resistivity and ultra-sound probes is complicated by the requirement of a surface couplant. With the exception of the Colebrand resistivity probe where couplant is automatically pumped to the contact point, the application of the couplant must be considered as a separate yet simultaneous operation. The prospects for drilling and coring are the poorest, largely on account of the weight and substantial running vibration. Concrete dust collection will be difficult to automate on account of the need to collect and isolate a large number of samples, and clean collection equipment between sampling.

Some probes, such as the half cell, are of a delicate construction and thus require limitation of contact forces. Motion, position and orientation control will be needed to operate on a closed loop basis, with sensors feeding back details of surface topology and irregularities in it. Concerning the relative importance of inspection methods, Fig. 3 which is based on the industrial survey findings, indicates only a small range in this. Clearly an AIF's chances of success will depend on the number of different inspection tasks it can perform.

5. TALL BUILDING ACCESS

For wide applicability, the form of the AIF support vehicle must be related to the surface features of actual buildings. A cursory review of tall building forms reveals a range of complexity in surface geometry, flat, continuous surfaces placing least demands on access. The typical buildings shown in Fig. 4 possess a number of common surface features, including recesses, balconies and protruding columns. To be applicable to such buildings, it is clear that inspection probes would need to be delivered to both horizontal and vertical surfaces.

In existing practice, abseiling or suspended vehicles are used for access, and it is similarly likely that a suspended vehicle is the most appropriate for automation. This form of vehicle has been used in commercially successful automation of wall tile sounding 7 , crack detection8 , and painting 9. Whilst a range of robot vehicles have been produced for wall climbing [e.g. 10], most of these require continuous unobstructed surfaces. Even those which are able to move between surfaces and negotiate obstacles11,12, are unlikely to be taken up on account of their dependence on suitable surfaces for suction grip, slow manoeuvring, high running noise and reduced payload under the necessary provision of onboard vacuum generation.

The most promising form of suspended vehicle is probably the Tirfor system. This has computer controlled positioning and a counter balance mechanism which enables the support structure to reach into recesses. Assuming a suitable manipulator could be mounted on such a vehicle, then considerable flexibility would be achieved in the access provision.

6. AUTOMATION BENCHMARKS

In the authors' opinion, little progress will be achieved in tall building inspection automation until the tasks are precisely defined and accepted as the focal point for research and development. To this end, the 'benchmark' concept is introduced, this being a clearly defined task goal which prospective AIFs must satisfy. Table 2 and Fig. 5 illustrate a typical benchmark of which many are under development. In developing these, a large, representative range of building surface geometries are under consideration with the various inspection tasks performed on them. It is intended that benchmarks will be sufficiently demanding so that an AIF achieving satisfactory performance in them could be expected to perform satisfactorily on the majority of tall buildings in Europe. Each benchmark will comprise a method statement for operating the inspection probe, target location and linear/area coverage, sampling patterns and inspection data requirements.

The robot simulation facility GRASP is being used to build the tall building library from which geometry for the benchmarks is extracted. At a latter stage, various AIFs will be incorporated into this facility and evaluated in terms of their ability to complete benchmark tasks and cycle time.

Apart from serving the needs for benchmark development and simulated AIF trials, building models could usefully be employed in AIF runtime operations and post-processing of survey data. To meet these requirements, the building models should be set in hierachical frameworks which enable assemblies or individual components to be readily isolated.

7. MAN-MACHINE INTERFACE

The MMI provisions for construction robots vary considerably in sophistication. The simplest type support only drive functions, relying on the operator to observe and correct motion as necessary [e.g. 13]. By contrast, advanced types use AI logic to support path planning, progress monitoring and extensive system diagnostics[14,15]. In the case of a remotely operated AIF, where data collection is the prime objective, the MMI must additionally support monitoring, verification and storage of the accumulated data. The organisation of data files will be a key issue, as the operator may wish to review and compare data sets.

Ideally, a graphical interface should be incorporated which assists the operator in his understanding of the AIF's activity and its position relative to the building surface. This can be achieved by combined use of the AIF's actuator sensing and vehicle location sensing. A number of location sensors will required so that different features can be used as reference objects. Alternatively, a ground based tracking facility could be employed to determine the vehicle location and orientation. For real-time implementation it will be necessary to adopt compact and fast retrieval graphical models of the type used in image processing applications . An application based on these ideas is currently being developed for a rebar locating robot .

8. CONCLUSIONS

For progress in tall building AIF development it is necessary that the nature of building defects and the methods employed to determine the underlying causes are understood. Whilst there is similarity between the operation of different inspection probes, they merit individual consideration for automation. The form of access support vehicle is an important issue, the most generally applicable being some form of suspended vehicle. For successful introduction into survey programmes, the AIF's role should be viewed as supportive rather than central. In this, prospects will be enhanced if production version costs are modest with accuracy, reliability and productivity assured. A further factor for enhancement is the MMI provision which should be activity centred rather than device supportive.

A benchmark concept has been introduced by which AIF goal tasks are precisely defined in terms of activity and location. It is hoped that these will be valuable in AIF research and development.

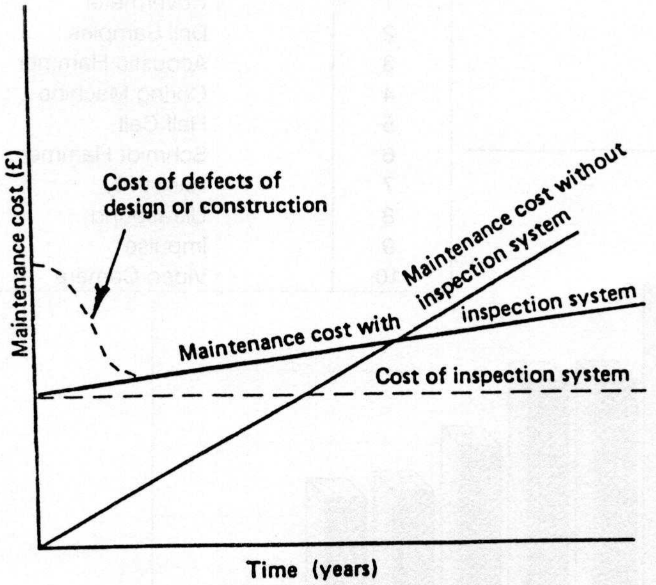


Figure 1. Cost relationship between inspection and without inspection system[4]

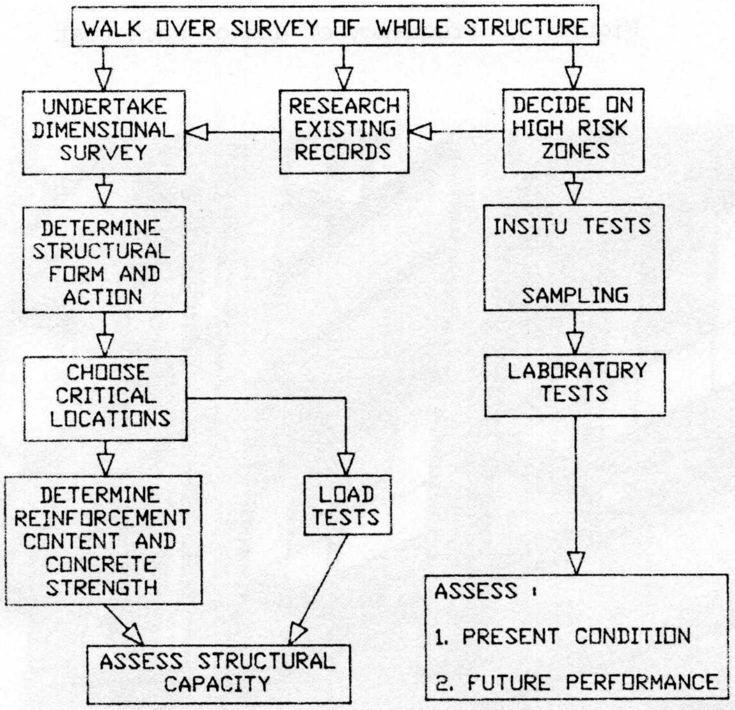
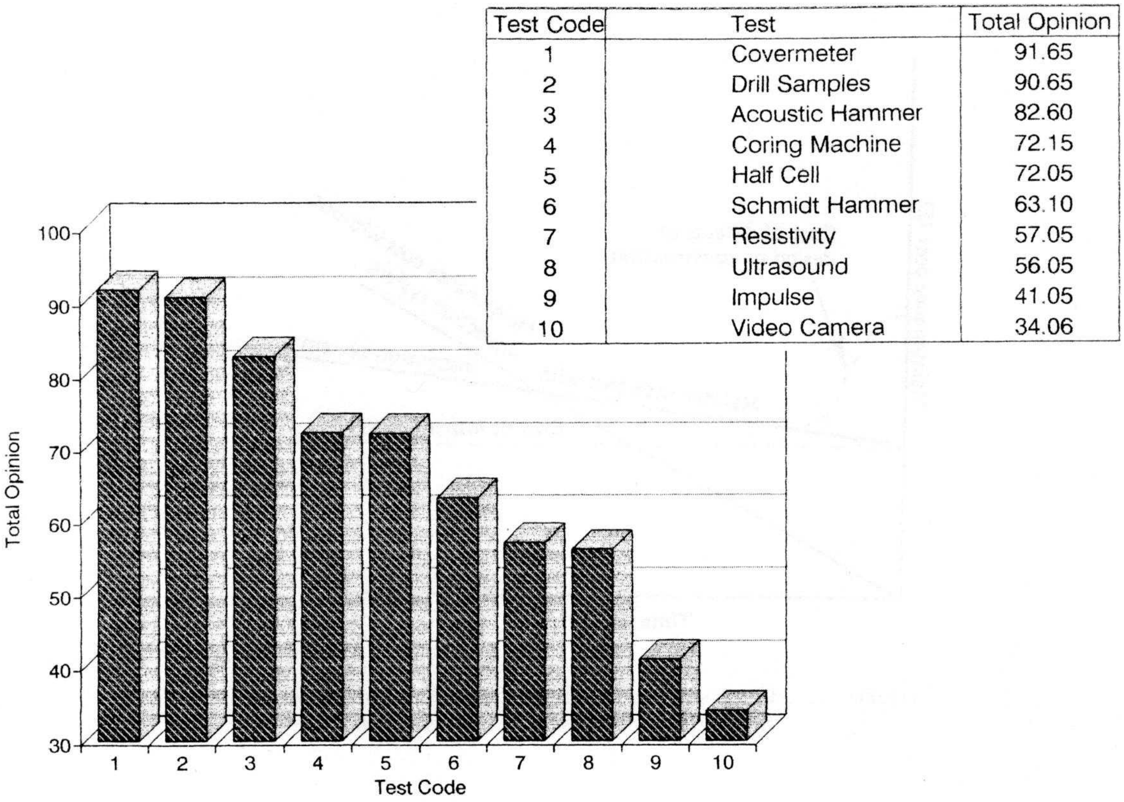


Figure 2 Assessment and Renovation of Concrete Structures[5]



Test Code	Test	Total Opinion
1	Covermeter	91.65
2	Drill Samples	90.65
3	Acoustic Hammer	82.60
4	Coring Machine	72.15
5	Half Cell	72.05
6	Schmidt Hammer	63.10
7	Resistivity	57.05
8	Ultrasound	56.05
9	Impulse	41.05
10	Video Camera	34.06

Figure 3. Frequency of use of each test

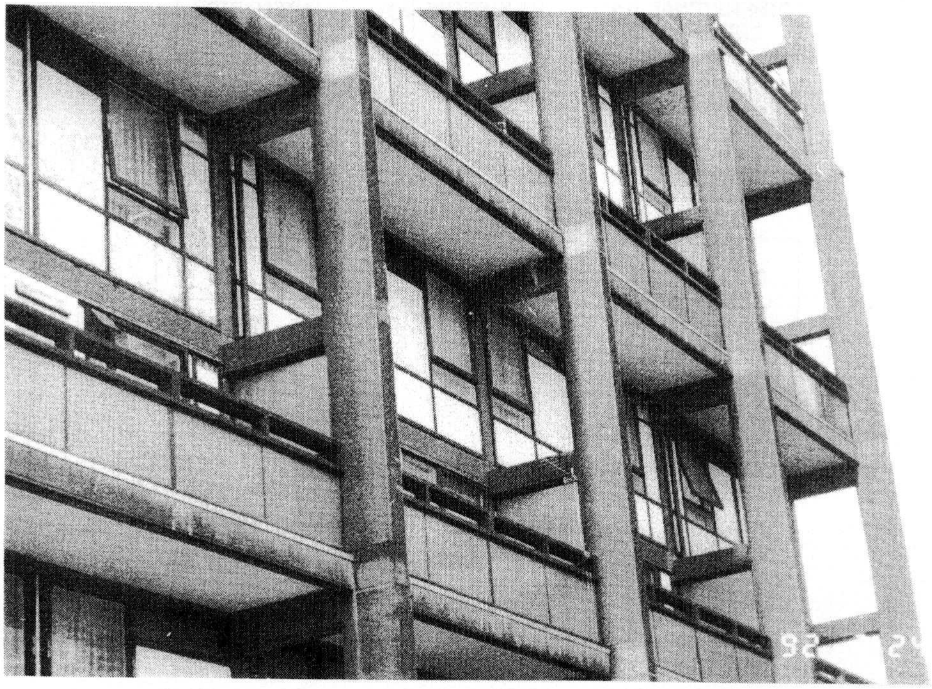


Figure 4. Typical features of UK's tall building showing recessess and protruding columns

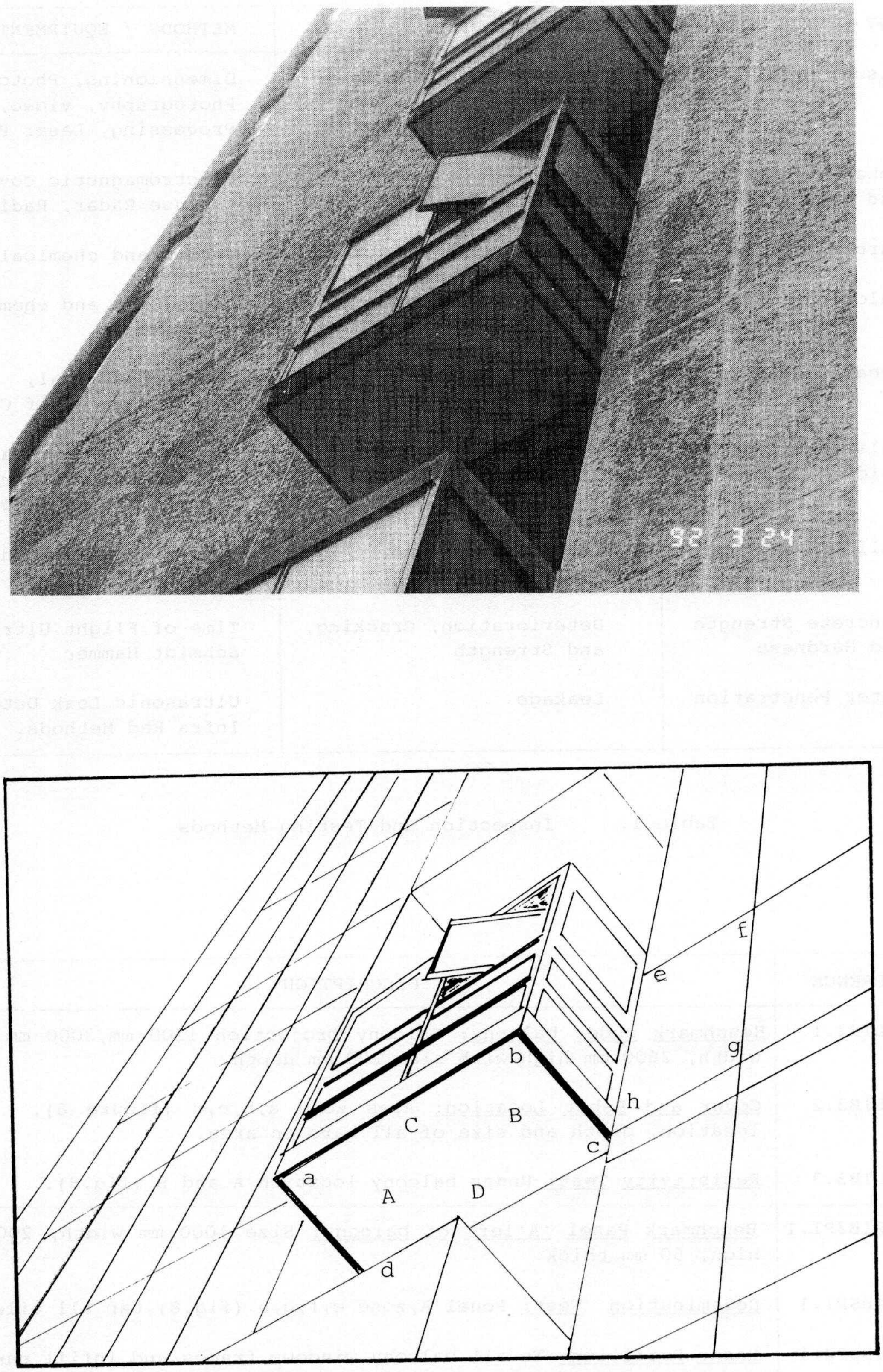


Figure 5. Automated Inspection Benchmarks

ELEMENT	FACTORS	METHODS / EQUIPMENT
1. Visual Defects	Cracks and Geometrical Defects	Dimensioning, Photogrametry Photography, video, Image Processing, Laser Profiling
2. Rebar Defects and contents	Rebar location and cover depth	Electromagnetic covermeter, Impluse Radar, Radiography.
3. Carbonation Test	Depth of Carbonation	Coring and chemical analysis
4. Chlorination Test	Chloride contamination	Drill Dust and chemical analysis
5. Rebar Corrosion	Extent of rebar corrosion	Electropotential, Resistivity, Half Cell
6. Delamination and Voids	Voids, Render, Cover, Tiles, Delamination	Acoustic Hammer, Tapping, Impulse Radar, Ultrasonic Testing, Pull-off Test
7. Wall Tie Failure	Corrosion of Ties, Missing Ties	Metal Detection, Endoscope
8. Concrete Strength and Hardness	Deterioration, Cracking, and Strength	Time of Flight Ultra-sound, Schmidt Hammer
9. Water Penetration	Leakage	Ultrasonic Leak Detector, Infra Red Methods.

Table 1. Inspection and Testing Methods

REFERENCE	DESCRIPTION
AESL1B3.1	Benchmark under balcony: Balcony projection 1200 mm,3000 mm width, 2600 mm high with slab 200 mm depth.
AESL1B3.2	Cover and Rebar Location: Area zone a,b,c,d (figure 8), location, depth and size of all bars in area.
AESL1B3.3	Resistivity Test: Under balcony location A and B (fig.8).
AESL1B3P1.1	Benchmark Panel 'A'left of balcony: Size 1000 mm width, 2000 mm high, 50 mm thick.
AEL1BSP1.1	Delamination Test: Penel A,zone e,f,g,h (fig.8),tap all tiles.
AEL1BSP2.1	Laser Profiling: To all balcony windows,frames and infill panels. scan for sealant defects.

Table 2. Automation Benchmarks

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