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# WORKER SAFETY AND ENVIRONMENTAL PROTECTION IN AUTOMATED STEEL BRIDGE RESTORATION

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**Abstract**

The aim of the paper is to review and evaluate current legislation on health and safety and environmental protection in the context of proposed technologies in bridge restoration.

Concerning health and safety, the main considerations are a new method of access, the use of robotic manipulators in surface preparation and painting, and the handling of hazardous waste. Containment and the use of recyclable abrasives are the main agencies for environmental protection. The study covers both Europe and the USA where greater progress has been achieved in the legislative provisions. It is intended that the outcomes will contribute to the development of the unification of health and safety and environmental protection provisions within Europe.

## 1. INTRODUCTION

The trend in the surface preparation industry is towards recyclable and environmental protective techniques. As a result of present environmental and worker safety legislation, this trend is likely to become more significant in the future.

Various new approaches to surface cleaning through breaking down interfaces are currently under investigation worldwide. Separate studies are carried out on automation potential in concrete and steel inspection, maintenance and repair. Environmental issues and increasing health and safety awareness are also becoming high on the construction industry's agenda. Therefore undertaking a project which could provide an enclosed and potentially highly automated working unit on structures with hazardous and expensive access, seems logical and indispensable.

The system should correspond to the characteristics and geometry configurations of the structure, type of activity to be performed and environmental protection through its' ability to house the pollutants from any repair or maintenance process. Several aspects of the proposed unit contribute to the improvement of health and safety and environmental protection, such as:

(i) improvement of remedial treatments to the structures with hazardous and costly access; (ii) introduction of innovative applications of new technologies (recyclable abrasives, new methods of surface treatments); (iii) reduction of health hazards (safe access, automation) and (iv) environmental protection (control of hazardous debris).

## 2. STATE-OF-THE-ART

The proposed system will integrate a number of sub-systems technologies. The main component of the unit under investigation is the multi-dimensional configuration of a mobile, modular access platform, tailor-assembled to the individual structure requirements [1]. The choice of decking to the platforms gives the option for recovery of the waste, therefore presents the opportunity to use recyclable abrasives [2]. A flexible containment built onto the platform provides the measures to enclose and separate the working environment and house the pollutants from any repair or maintenance process. The multi-dimensional configurations of platforms, tailor-assembled to the individual structure requirements with the choice of decking give the option for recovery of the waste or recyclable abrasives. The containment will effectively separate the working environment and enable the use of automation for NDT and maintenance.

Efforts to eliminate the human factor will be directed towards introduction and modification of existing articulated arm manipulators. The automated arm is fixed to a work-class Remotely Operated Vehicle (ROV) and the system is placed at the workplace and locked into position on the platform (see Fig.1). Tasks can be done by a human operator with computer assistance, or automatically by the computer under operator supervision. The computer system graphics allow the operator to see the arm, tool and workpiece in areas out of sight of ROV mounted cameras. The graphic system also allows the manipulator to operate in poor visibility. The final automated facility will provide an enclosed and potentially highly automated working unit for restoration tasks on steel bridges (see Fig.2).

The following aspects were addressed while designing the system:

(i) overview and assessment of the surface preparation methods using recyclable abrasives;(ii) analysis of access requirements for structures under investigation;(iii) assessment of the properties and flexibility of the Beeche Modular Space Frame platforms and Mechano Systems in connection with access requirements;(iv) Investigation into automation potential of NDT and some maintenance and repair techniques;(v) based on the outcome of previous stages, the specification and design proposal for the containment to be assembled addressing the structural requirements, range of activities and suitability;(vi) risk analysis and reduction in health hazard due to application of automation and recycling abrasives and (vii) identifying the gains from an environmental perspective, such as the reduction in amounts of hazardous waste and reduced pollution.

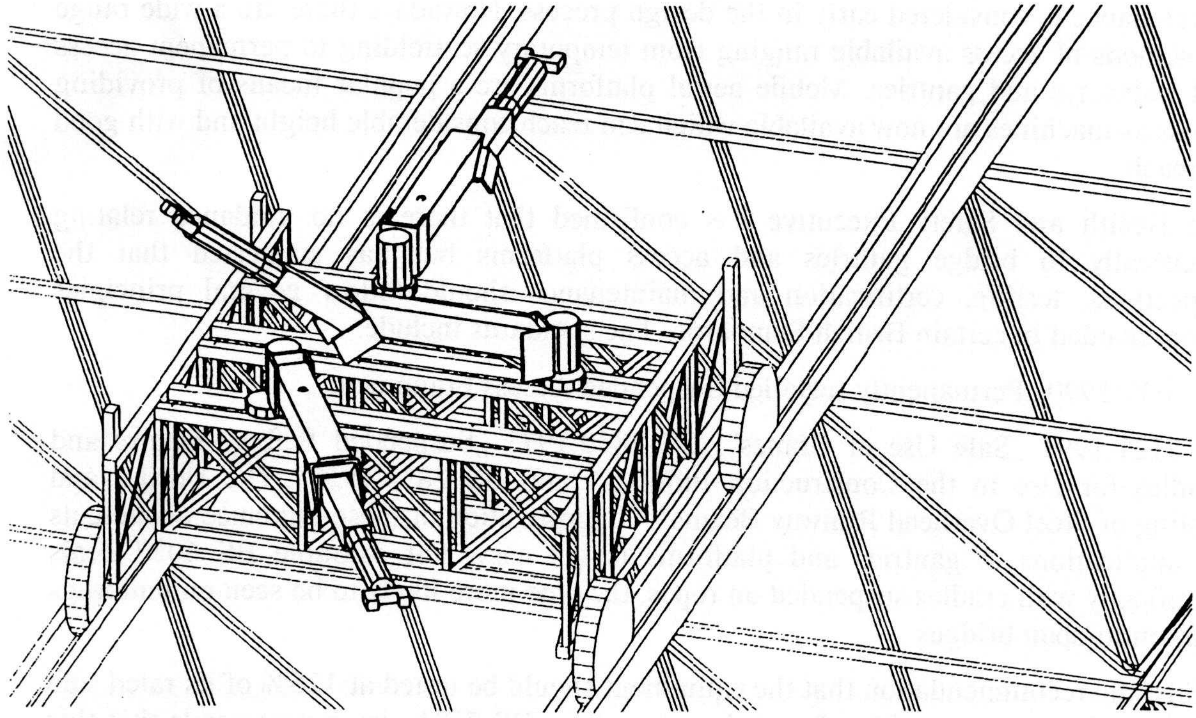

**Figure 1** The Proposed System on the Beeche Platform.

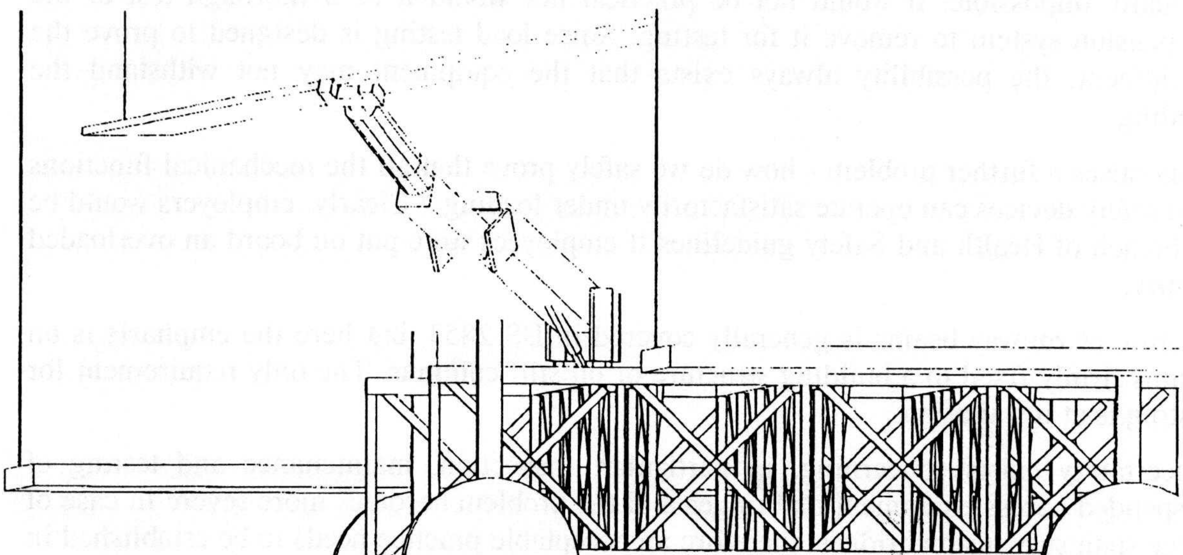

**Figure 2** The Proposed System Working on a Bridge.

## 3. ACCESS PROVISIONS AND SUSPENDED ACCESS EQUIPMENT

**A bridge owner has a responsibility for the safety of those who use his structure as well as those passers-by who might be affected by partial or complete collapse of the structure. The method proposed for providing access to a structure for inspection and**

maintenance is considered early in the design process. Nowadays there are a wide range of methods of access available ranging from temporary scaffolding to permanent access and walkways and gantries. Mobile aerial platforms are a popular means of providing access as machines are now available which can reach considerable height and with good outreach.

The Health and Safety Executive has confirmed that there is no guidance relating specifically to bridge gantries and access platforms but has suggested that the inspections, testing, certification and maintenance should follow general principles recommended in certain British Standards. The standards include:

BS 6037:1990 „Permanently Installed Suspended Access Equipment",

BS 7121:1991 „Safe Use of Cranes", BS 2830:1973 „Suspended Safety Chairs and Cradles for Use in the Construction Industry" and BS 2853:1957 „The Design and Testing of Steel Overhead Runway Beams". Interpretation of these guidance documents for applications to gantries and platforms is not easy. For example BS 6037 deals specifically with cradles suspended on ropes, the type more likely to be seen on buildings than multi-span bridges.

Whilst the recommendation that the equipment should be tested at 125% of its rated safe loading is in common with other codes on testing, BS 7121 also recommends that this should be done with the load just above ground level. This is seldom possible with bridge access platforms and gantries and in the case of the large span suspension bridges, virtually impossible. It would not be practical nor would it be a thorough test of the suspension system to remove it for testing. Since load testing is designed to prove the equipment, the possibility always exists that the equipment may not withstand the loading.

This raises a further problem - how do we safely prove that all the mechanical functions and safety devices can operate satisfactorily under loading ? Clearly employers would be in breach of Health and Safety guidelines if employees were put on board an overloaded gantry.

Testing of runway beams is generally covered in BS 2853, but here the emphasis is on beams firmly fixed to a building structure or on stiff columns. The only requirement for testing is at installation.

Uncertainty exists concerning, in particular, inspection, maintenance and testing of suspended access equipment on bridges and the problem becomes more severe in case of large span suspension bridges, therefore an acceptable practice needs to be established in the area.

The EEC European Standard Committee is fully aware of the gap in the legislation.

## 4. DESIGN OF ENCLOSURES

During surface preparation, airborne particles and debris from the removal of paint (particularly paints containing lead, cadmium and chromate pigments) can contaminate the air, soil and water surrounding work sites. The potential environmental hazards can be reduced by containing the debris. Federal State Regulations in USA classify types of containment in relation to quantity and type of dust and debris (Classes 1 to 4)[3].

Individual tables identify the components for each of the classes according to the type of removal method.

For example Class 1 provides the greatest level of emission control and requires air impenetrable walls, fully sealed joints, airlock or resealable entryways,and exhaust air filtration. This type of containment is recommended for abrasive blast cleaning, although is the most expensive. Due to the cost impact and the practicality, Class 2A is normally accepted, although it is allowing only partially sealed entryways. Some additional factors may have been taken under consideration, such as type of structure, location, climate, proximity to other buildings, additional work to be performed inside the containment (e.g., paint spraying). The components and materials of containment enclosures are also identified and finally methods of assessing efficiency of debris collection and abrasive recovery.

In UK, the Environmental Protection Act 1990 (EPA), although introduces a new Pollution Control System in Part 1, reforms waste disposal in Part 2 and controls the use, import, containment or release of pollutants to the environment, does not specify the exact guidelines for designing of enclosures.

## 5. SURFACE CLEANING

In this process, hard, small abrasive particles strike the steel or other substrate at high velocities, fragmenting the abrasive particle and eroding the substrate. Significant quantities of dust from the abrasive and the surface debris are thus made airborne and can contribute to air pollution. This dust itself is recognized as a fugitive emission that is often regulated. In addition, specific species may be released, such as lead dust, other heavy metals, silica, or asbestos, which are separately controlled by environmental agencies.

### 5.1 H&S in Surface Preparation

Surface cleaning through breaking down interfaces (sand, steel grid and plastic pellets blasting) is referred to in International Standards ISO 8501/2/3/4. But only in ISO 8504 on 'Surface Preparation Methods', there is a small clause 4.2.2 which refers to equipment, materials and abrasives being dangerous or harmful and therefore to be observed in national regulations.

### 5.2 Environmental Impact

Environmental issues relate to release into the air or water and disposal of the heavy metals used in bridge coatings copper, cadmium and lead.

In United Kingdom, the Environmental Protection (EP) Act introduces major new regulatory frameworks in Parts 1 and 2 dealing with Integrated Pollution Control (IPC) and Waste (IWC). The basic premise of IPC is that the impact of pollution must be considered for the environment as a whole, however, the approach which underpins IPC is limited and there is no general duty on owners and controllers not to pollute the environment. IPC is limited to prescribed processes by prior authorizations, which are based on legal requirement for owners and controllers to prevent prescribed substances from being released or released at the level considered as 'harmless'. In order to achieve these aims, operators will have to use the „best practicable means not entailing excessive cost" (BATNEC), which has a basis in law derived from the 1984 European Directive on industrial air pollution.

In USA, the Environmental Protection Agency's (EPA) authority to issue and enforce environmental regulations is based on the environmental statutes or laws passed by the US Congress. The ones which have had the greatest impact are the Clean Air Act, the Resource Conservation and Recovery Act, and the Toxic Substance Control Act.

### 5.2.1 Air Pollution Control Regulations

UK - „Air" became the central public face of industrial pollution and the origins lay in the mid 19th century. EP Act prescribes number of processes subject to IPC with legally binding emission limits and a residual duty to use the 'best practicable environmental option' (BPEO) for controlling pollution. Additionally, Part 1 establishes the new regulatory framework for air pollution only. Whilst Her Majesty's Inspectorate on Industrial Pollution (HMIP) will be drawing up Guidance Notes and Regulations which will contain emission standards in order to regulate their reinforcement of IPC, the EP Act also gives the Secretary of State powers to intervene in the process.

USA - a. Clean Air Act - The original Clean Air Act (CAA), passed in 1970, focused on several specific pollutants: sulfur dioxide, carbon monoxide, nitrogen dioxide, particulates, ozone and lead.[4]

b. Clean Air Act Amendments - The Clean Air Act Amendments of 1990 (CMA) require areas that are not in compliance with existing requirements for ozone, carbon monoxide and particulates to come into compliance, and provide a schedule for compliance.[5] The Amendments also require control of air toxins, approximately 190 specific substances emitted by specific kinds of facilities. Many of the solvents that make up paint will be affected by both of these sections of the Clean Air Act Amendments.

### 5.2.2 Water Quality Regulations

USA - Clean Water Act - The Federal Water Pollution Control Act of 1972 was the first legislation. Amendments of 1987 expanded the number of regulated pollutants to include 129 specific toxic pollutants.[6]

Requirements are enforced through a permit system. Facilities must have a permit to discharge materials to waterways. There are some exceptions for facilities discharging to public wastewater treatment facilities.

### 5.2.3 Hazardous Waste Regulations

Both coating removal and coating application generate waste products, which must be properly disposed of. In many instances, the waste may be classified as hazardous because of the heavy metal (e.g., lead) content of the residue, or the solvents of unused paint or thinner.

UK - Part 1 of IPC system controls emissions to land or water, while Part 2 reforms waste disposal.

USA - The storage of certain products (e.g., hazardous waste, petroleum compounds) is regulated by EPA because of the potential ecological damage that could result from a spill or leak from storage vessels. The above activities collectively can affect almost all the major environmental receptors (i.e., air, soil, groundwater, surface water, potable water).

a.Resource Conservation and Recovery Act - The Resource Conservation and Recovery Act (RCRA), passed in 1976, was intended to provide management of hazardous wastes.[7] Generators were required to evaluate all wastes generated; to identify those that were hazardous; and to properly store, transport and dispose of those that were determined to be hazardous waste.

b.The Superfund Amendments and Reauthorization Act- The Superfund Amendments and Reauthorization Act (SARA), passed in 1986, reauthorized, refunded and refocused hazardous waste site clean up. It required industries to report quantities of hazardous substances released into air or water or stored on site to these local agencies and to the federal government.

### 5.2.4 Worker Protection Clothing

There is imperative, according to USA regulations, that the abrasive blast operator wears a National Institute for Occupational Safety and Health/Mine Safety and Health Administration (NIOSH/MSHA) approved type CE positive pressure air supplied blast hood.

## 6. SURFACE RESTORATION (PAINT SPRAYING)

In the process of spraying (and other means of application), a substantial portion of the liquid coating does not reach the substrate but is lost due to overspray. In addition, most coatings have appreciable quantities of volatile organic compounds (solvents) that can contribute to smog formation. However, many of the newer, high technology coatings, such as zinc-rich primers, vinyls, high built coatings require spray techniques. Airless spray technique allows the use of more viscous materials than conventional spray. Concern over restrictions on solvent emissions has stimulated interest in water borne coatings.

In USA safety precautions issued by the American National Standards Institute (ANSI), the National Safety Council (NSC) and SSPC-PA Guide 3 'A Guide to Safety of Paint Application' should be practiced.

## 7. RISK ASSESSMENT

There is no universally agreed, precise definition of the term 'safe'. It has been recognized that accepting certain system as 'safe' would mean actually a sensible balance between risks, benefits and costs. What can be accepted as tolerable risk depends largely on political and legal considerations which should also be influenced by public concerns.

The development of robots for unstructured environments relies on two domains of mechanical control: the development of robots and guided vehicles and the development of telemanipulators. This means in practice providing telemanipulators with the capability of carrying out certain tasks, unsupervised and vehicles to be driverless, with the ability to navigate without recourse to artificial beacons. Achieving such systems requires the synthesis of several technologies.

The development of any new technology poses problems in conforming to the existing legislation due to them being inadequate to cope with the new problems. Therefore these areas for safety consideration need to be considered (hazards posed by applying automation, suspended access, new surface treatment techniques). These new potential sources of danger should be assessed using risk analysis methods. The purpose of the risk assessment is to identify the probability and severity of a hazard in order to be able to compare it with 'agreed' acceptable risk. The risk analysis involves the examination of a set of conditions to determine the probability of occurrence of a hazardous event which can lead to damage or injury.

The range of existing risk analysis techniques covers:(i) Hazard and Operability Study Technique - HAZOP, for the process industry; (ii) Failure Mode and Effects Analysis - FMEA with its variant - Failure Modes, Effects and Criticality Analysis - FMECA; (iii) Fault Tree Analysis - FTA; (iv) Event Tree Analysis - ETA; and (v) Consequence Led Analysis of Safety and Hazards - CLASH.

Risk assessment technique, such as FTA identifies the processes which could initialize the disastrous chain of events and these are then plotted as logical sequences or Fault Trees. The performance of the safety features can then be analyzed. However, before the analysis can begin, all failure modes have to be identified, for example by FMEA.

ETA operates in the opposite direction to FTA and begins with the initiating event and then follows through a series of subsequent events to a set of outcomes. This technique is useful in identifying outcomes, that rely on the interaction of failures and other events, such as time sequence.

FMEA and FMECA techniques depend on the availability of quantifiable failure rates in components and a simple relationship between a failure mode and a hazardous event.

For some Programmable Electronic Systems (PES) it is particularly difficult to adequately model the system to take account of all possible software failure modes, as these depend on interactions between modules and particular sets of external events, which increases the number of permutations in possible conditions, making the complete analysis often impossible.

HAZOP, in turn, investigates the consequence on safety of deviations from the intended design conditions (e.g.variations in temperature, or pressure). The deviations with realistic causes and consequences are the possible hazards.

Finally, CLASH is the most recent development. The list of keywords is established for each type of hazard, for example: mechanical hazards cover „crushing", „shearing", „trapping", etc.; electrical - „electrocution", „arching", etc.; noise - „hearing loss", 'interference with speech' and so on. These guidewords are used together with HAZOP (identifying risks) and followed by FTA to establish causes of the risks. The use of FMECA is then proposed, following several repetitions of the two previously mentioned methods, having reduced the number of severity of risks to establish an order of criticality of those, that remain.

Numerical quantification of risks is very difficult and subjective. However, the risk of an accident occurring can be overcome by training and following safety procedures for each activity. Safety procedures, in practice, are developed through imagining the risks, assessing them and considering ways of minimizing. Level of competence will obviously affect the classification of risk severity.

# 8. SAFETY ASSESSMENTS

## 8.1 Safety Assessment for the Automated Arm Manipulator

### 8.1.1 Safety Procedure for Approved Personnel Prior to Operation of Inspection Robot

All the safety precautions should be carried out before entering the robot operation area.

i) Inform all relevant authorities and persons likely to be affected, of proposed use of robot and any necessary precautions to be taken;

ii) Check that telephone is available nearby and that emergency services numbers are also available;

iii) Check that fire extinguisher is available in close proximity to robot enclosure;

iv) Ensure that at least one person present is trained in First Aid;

v) Before moving the robot to operating area, check access route for obstacles and assess the number of persons needed to safely move the robot to the operating area. The number of persons needed to carry the robot should be based upon the figure of a maximum safe load for each person of 20kg.;

vi) All persons involved should wear appropriate safety wear: safety-helmets; gloves; safety footwear and one-piece overalls;

vii) Two-way radios should be available for communicating between the ground and roof level in appropriate situations, e.g. taller bridges, noisy locations, high winds.

viii) A recognized hand-signalling system should be used between those communicating between ground and platform or bridge deck and vice-versa.

### 8.1.2 Precautions to be Taken Before Starting the Robot

i) Examination of the robot for visible faults;

ii) Make sure that warning signs are displayed. Warning sound or flashing light when intruder enters area of operations, robot motion should cease until intruder leaves area;

iii) Check that the clamps on the bridge and access platform are secured and check cables for any signs of damage.

iv) Ensure winch and fixing devices operators are competent and are aware of safety precautions. A safety harness should be provided for their use;

v) Make sure ground and bridge areas in operating zone are free of hazards e.g. water, oil, grease, loose cables and other substances and objects;

vi) One person at ground level to guide passers by away from the hazardous area;

vii) Check that robot is securely connected to the platform.

### 8.1.3 Procedure to Be Followed in the Event of Robot Malfunction

In the event of the robot carrying out some unprogrammed action e.g. suddenly stopping, or in the event of some unforeseen problem occurring, then it should be isolated from its power source. The robot having been manually lowered to the ground the technician should then approach it to assess the problem.

### 8.1.4 Procedure to Be Followed in the Event of an Accident

i) Isolate power from robot;

ii) Lower robot to ground level;

iii) Person trained in First Aid attends to accident victim;

iv) If necessary, contact emergency services.

### 8.1.5 Procedure to Be Followed After Using the Robot

i) Move lifting equipment to the secured location;

ii) Lifting equipment at roof level should be secured from interference by unauthorized persons;

iii) Robot should be placed in secure area to avoid interference or tampering with.

iv) Any equipment associated with robot use should be removed from ground level area and stored for future use.

### 8.1.6 General Maintenance for the Robot

In order to ensure safe functioning of the robot it is important that a regular maintenance procedure is established. The following are some suggested guidelines, and not intended as a definitive solution:

i) A daily visual check with particular attention paid to key components such as moving parts and those areas that have proved problematic in the past;

ii) A weekly, more detailed inspection to ensure that all powered mechanisms are working properly and that any hydraulic systems are free from obvious leaks, defects etc.;

iii) A thorough inspection of the complete system should be carried out annually;

iv) The person carrying out these maintenance inspections should be fully trained and authorized for the purpose. A written record of all maintenance inspections should be kept.

## 8.2 Safety Assessment of the Access Platform

i) Only fully trained and competent persons should be allowed to operate, work from or carry out any work associated with the erection of the Access Platform;

ii) Potential employees should undergo medical screening to assess their suitability for the work;

iii) Precautions should be taken to ensure that traffic on the river is diverted from passing under the platform when work is taking place;

iv) If night work is being is being carried out the work platform should be well lit to ensure safe working conditions;

v) In order to maintain stability loads should be uniformly distributed over the platform area. Signs should be displayed stating the maximum safe load that can be placed on the platform;

vi) The maximum permissible wind speed in which working from the platform is permissible should be adhered to;

vii) The platform floor should be slip resistant;

viii) Suitable securing points for safety harnesses should be provided;

ix) Provide a safe means of getting to, and from the platform. Any access ladders should be well secured;

x) Regular checks of the Trolley Suspender Assembly should be made;

xi) Safety equipment such as safety harness, safety helmets, masks, gloves and footwear should be worn by all persons working on the platform;

xii) A means of communication between the platform and the ground should be made available for general and emergency use;

xiii) The platform should be kept tidy and clear of obstacles at all times;

xiv) A fire extinguisher and First Aid Kit should be available at all times;

xv) Warning signs should be displayed on the bridge, in order to protect those working on the bridge top from the danger posed by traffic.

**CONCLUSIONS**

Tight monitoring of the pollution levels in large maintenance and repair contracts on big scale structures will ensure that the outcome of this study will not be ignored by the industry. On the other hand proving the substantial savings due to automation, reduced time-scale of the contracts and safer working conditions will attract wider interest from the industry.

Benefits to the industry can be summarized as follows: (i) safer working space,(ii) reduction in cost due to automation, re-usable nature of access equipment and enclosure,(iii) cost saving due to the possibility of housing and using recyclable abrasives and (iv) time saving, therefore reduced closure times of bridges and viaducts.

Whilst benefits to the public would be: (i) significantly less dust, (ii) reduction in the amount of hazardous waste released to the atmosphere and (iii) less noise due to automation and nature of the enclosure.

Remote handling devices and techniques will be employed, which incorporate technology developed for hazardous and harsh environments. Productivity will be improved as remote handling equipment will enable heavier and more powerful tools to be used. Also, the adoption of cleaner processes will simplify and substantially reduce the cost of workplace containment. Robust sensor technology will be used to help overcome the subjective problems in surface assessment and classification as well as to facilitate real time quality assurance. The design of restoration projects will be based on the whole life costs of the bridge operation and restoration cycle, and thus be more reliable and cost effective.

The described unit would address the integration of whole process derived from full consideration of the options.

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