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Aerodrome Design Manual

Part 6
Frangibility

Approved by the Secretary General
and published under his authority

First Edition — 2006

International Civil Aviation Organization

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AMENDMENTS

Amendments are announced in the supplements to the *Catalogue of ICAO Publications;* the Catalogue and its supplements are available on the ICAO website at www.icao.int. The space below is provided to keep a record of such amendments.

RECORD OF AMENDMENTS AND CORRIGENDA

AMENDMENTS		
No.	Date	Entered by

CORRIGENDA		
No.	Date	Entered by

FOREWORD

Proper design and installation of visual and non-visual aids (e.g. approach lighting towers, meteorological equipment, radio navigational aids) are prerequisites for the safety and regularity of civil aviation. At airports, various visual and non-visual aids are located near runways, taxiways and aprons where they may present a hazard to aircraft in the event of accidental impact during landing, take-off or ground manoeuvring. All such equipment and their supports shall be frangible and mounted as low as possible to assure that impact will not result in loss of control of the aircraft.

Much of the material included herein is closely associated with the specifications on frangibility of visual and non-visual aids contained in Annex 14 — *Aerodromes*, Volume I — *Aerodrome Design and Operations* and Volume II — *Heliports*. The purpose of this manual is to assist States in the implementation of these specifications and thereby help to ensure their uniform application.

Annex 14 — *Aerodromes* contains both Standards and Recommended Practices for objects to be made frangible. However, since the objective of this manual is to provide guidance on frangible design, distinction between the two types of specifications will not be made.

The manual incorporates guidance material on the design, testing and installation of frangible structures at airports and heliports and is based on the conclusions of the Fifth and Sixth Meetings of the ICAO Frangible Aids Study Group held in 1998 and 2003, respectively, as well as on current practices of several States.

It is intended that the manual be kept current. Future editions will be improved on the basis of the results of the work of regulators, industry and airport operators as well as on the basis of experience gained and comments and suggestions received from users of this manual. Readers are therefore invited to give their views, comments and suggestions on this edition. These should be directed to the Secretary General of ICAO.

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Chapter 1

INTRODUCTION

1.1 DEFINITIONS

Frangible object. An object of low mass designed to break, distort or yield on impact so as to present the minimum hazard to aircraft.

Impact load. A sudden application of a load or force by an object moving with high velocity.

Break-away or failure mechanism. A device which has been designed, configured and fabricated in such a way that it is very sensitive to one type of loading, usually resulting from a time dependent dynamic impact, but immune to the normal environmental and operational loads imposed on the mechanism during the lifetime of the structure. The "break-away mechanism" can be designed in conjunction with the joints of the structure and/or designed independent of the joints of the structure.

Impact energy. The energy required for an object to break, distort or yield when subjected to an impact load.

1.2 WHAT IS FRANGIBILITY

At airports, various visual and non-visual aids (e.g. approach lighting towers, meteorological equipment, radio navigational aids) are located near runways, taxiways and aprons, where they may present a hazard to aircraft in the event of accidental impact during landing, take-off or ground manoeuvring. All such equipment and their supports should be frangible and mounted as low as possible to ensure that impact does not result in loss of control of the aircraft. This frangibility is achieved by use of lightweight materials and/or the introduction of break-away or failure mechanisms that enable the object to break, distort or yield under impact.

1.3 OBSTACLES TO BE MADE FRANGIBLE

1.3.1 Obstacles are defined as all fixed objects, or parts thereof, that are located on an area intended for the surface movement of aircraft or that extend above a surface intended to protect an aircraft in flight. The first objective should be to site objects so that they are not obstacles. Nevertheless, certain airport equipment and installations, because of their function, must be located in an operational area. All such equipment and installations as well as their supports should be of minimum mass and frangible in order to ensure that impact does not result in loss of control of the aircraft.

1.3.2 Annex 14 — *Aerodromes*, Volume I — *Aerodrome Design and Operations,* Chapter 5, specifies that elevated approach lights and their supporting structures should be frangible except that, in that portion of the approach lighting system beyond 300 m from the threshold:

a) where the height of a supporting structure exceeds 12 m, the frangibility requirement should apply to the top 12 m only; and

b) where a supporting structure is surrounded by non-frangible objects, only that part of the structure that extends above the surrounding objects should be frangible.

1.3.3 Annex 14, Volume I, Chapter 9, specifies that any equipment or installation required for air navigation purposes which must be located:

a) on a runway strip (instrument or non-instrument); or

b) on a runway end safety area; or

c) on a clearway and which would endanger an aircraft in the air; or

d) on a taxiway strip or within the distances specified in Annex 14, Volume I, Table 3-1, column 11);

should be frangible and mounted as low as possible.

1.3.4 Annex 14, Volume I, Chapter 9, also specifies that any equipment or installation required for air navigation purposes which must be located on or near a strip of a precision approach runway category I, II or III and which:

a) is situated within 240 m from the end of the strip and within:

  1) 60 m of the extended centre line where the code number is 3 or 4;

  2) 45 m of the extended centre line where the code number is 1 or 2; or

b) penetrates the inner approach surface, the inner transitional surface or the balked landing surface;

should be frangible and mounted as low as possible.

1.3.5 Furthermore, Annex 14, Volume I, Chapter 9, specifies that any equipment or installation required for air navigation purposes which is an obstacle of operational significance in accordance with 4.2.4, 4.2.11, 4.2.20 or 4.2.27 of the Annex should be frangible and mounted as low as possible.

1.3.6 Airport equipment and installations which, because of their particular air navigation function, have to be located in an operational area include:

— elevated runway, taxiway and stopway lights

— approach lighting systems

— visual approach slope indicator systems

— signs and markers

— wind direction indicators

— Instrument landing system (ILS) localizer equipment

— ILS glide path equipment

— ILS monitoring antenna

— Microwave landing system (MLS) approach azimuth equipment

— MLS approach elevation equipment

— MLS monitoring antenna

— radar reflectors

— anemometers

— ceilometers

— transmissometers

— forward-scatter meters

— fencing

Chapter 2

SITING CONSIDERATIONS

2.1 SITING OF EQUIPMENT

2.1.1 Guidance or specifications on the siting of navigational aids are contained in Annex 10 — *Aeronautical Communications,* Volume I — *Radio Navigation Aids,* and Annex 14 — *Aerodromes,* Volume I — *Aerodrome Design and Operations,* and Volume II — *Heliports,* and their related manuals. These should be taken into account when siting navigational aids. In general, equipment and security fencing should be sited as far away from the runway and taxiway centre lines as practicable.

Runway, stopway and taxiway edge lights

2.1.2 Runway, stopway and taxiway edge lights should be placed along the edges of the area declared for use as runway, stopway and taxiway, respectively, or outside the edges of these areas at a distance of not more than 3 m. Similarly, runway threshold and end lights should be placed in a row at right angles to the runway axis as near to the extremity of the runway as possible and, in any case, not more than 3 m outside the extremity. Elevated runway, stopway and taxiway edge lights are obstacles and therefore should be frangibly mounted.

Approach lighting system

2.1.3 An approach lighting system can only be located along the extended runway centre line. Annex 14, Volume I, specifies three types of approach lighting systems, i.e. simple, precision approach category I and precision approach categories II and III. All approach lighting systems begin at a specified distance from the runway threshold and extend outwards in the direction of approach to the runway. Where the threshold is at the extremity of the runway, the entire lighting system is elevated and the lights may constitute an obstacle to air navigation. Where the threshold is displaced from the extremity, that part of the system between the displaced threshold and the runway extremity is usually inset and as a result, the lights do not constitute an obstacle.

Visual approach slope indicator systems

2.1.4 A visual approach slope indicator system is required to be installed at a specified location near the runway. Annex 14, Volume I, includes specifications for two types of visual approach slope indicator systems: T-VASIS and PAPI (T-visual approach slope indicator system and precision approach path indicator, respectively). These systems consist of elevated light units located either on one or both sides of the runway at specified distances beyond the threshold. The number of light units involved and their disposition depend on the type of system. In general, the light units are located between 15 m and 42 m from the edge of the runway.

Signs and markers

2.1.5 Signs and markers need to be located as near to the edge of the pavement as their construction will permit for easier visibility by the pilot of an aircraft. Those located near a runway or taxiway need to be sufficiently low to preserve clearance for propellers and for the engine pods of jet aeroplanes. Those farther from the runway or taxiway need to be larger in order to provide for inscriptions large enough to be read by the pilot.

Note.— For further information on location of the visual aids discussed in 2.1.2 to 2.1.5, please refer to Annex 14, Volume I, Chapter 5.

Wind direction indicators (wind cones)

2.1.6 A wind direction indicator should be located such that the indicator is visible from aeroplanes in flight or on the movement area. This can be outside the areas mentioned in 1.3.3 and 1.3.4. A further consideration in selecting the site is that the indicator is free from the effects of air disturbances caused by nearby objects.

ILS localizer

2.1.7 The preferred location for the localizer antenna array is on the extended runway centre line beyond the far end of the runway. This location permits the radiated on-course signal to overlie the runway centre line. The following factors govern site selection:

a) coverage requirement;

b) type of localizer array;

c) obstacles or vertical reflecting surfaces within the desired localizer coverage volume;

d) obstacle clearance and missed approach criteria;

e) location of monitoring antenna; and

f) technical siting considerations.

ILS glide path antenna system

2.1.8 The lateral displacement of the ILS glide path antenna system should not be less than 120 m with respect to the runway centre line. The longitudinal location should be selected to place the ILS reference datum as close as possible to the recommended nominal value of 15 m above the threshold. In general, the following factors govern site selection:

a) desired operating limits with respect to approach speeds and rates of descent of aeroplanes;

b) the position of obstacles in the final approach area, the aerodrome sector and the missed approach areas, and the resulting obstacle clearance limits;

c) runway length available;

d) location of monitoring antenna; and

e) technical siting considerations.

Note.— For further guidance on siting discussed in 2.1.7 and 2.1.8, please refer to Annex 10, Volume I, Chapter 3 and Attachment C.

MLS approach azimuth equipment

2.1.9 The preferred location for the approach azimuth equipment antenna (analogous to the ILS localizer) is on the extended centre line beyond the stop end of the runway and on the extended centre line before the threshold for the back azimuth equipment antenna, if provided. The following factors govern site selection:

a) need for collocation with existing ILS localizer antenna array;

b) obstacle clearance and missed approach criteria;

c) multipath considerations;

d) possible interference problem when the MLS has to be located in the approach lighting area;

e) location of monitoring antenna; and

f) technical siting considerations.

MLS approach elevation equipment

2.1.10 The approach elevation equipment antenna (analogous to the ILS glide path) should be located offset of the runway. The location is selected so that the asymptote of the minimum glide path crosses the threshold at the MLS approach reference datum. The following factors govern site selection:

a) need for collocation with existing ILS glide path antenna;

b) obstacle clearance and missed approach criteria;

c) multipath considerations;

d) location of monitoring antenna; and

e) technical siting considerations.

2.1.11 In the case of ILS/MLS collocation, the MLS approach elevation equipment antenna should be positioned forward of the ILS glide path and outboard (further away from the runway centre line) or inboard (nearer to the runway centre line) of the ILS antenna.

Note.— For further guidance on the siting discussed in 2.1.10 and 2.1.11, please refer to Annex 10, Volume I, Chapter 3 and Attachment G.

Anemometers

2.1.12 In view of the usually flat, open aspects of most aerodromes, generally speaking, the surface wind flow over the runway or runway complex may be considered homogeneous. Surface wind observations should be representative of conditions at a height of 6 m to 10 m above the runway, and this usually means that the height of the anemometer mast itself is between 6 m and 10 m. Under normal circumstances, therefore, anemometers can be located outside the runway strip and should not penetrate a transitional obstacle limitation surface nor infringe taxiway strips. Where it is necessary to locate anemometers inside the strip in order to provide representative observations for landing and take-off operations, it is most unlikely (although not totally impossible) that local conditions would require siting closer than 60 m from the runway centre line. Hence, on runway strips that include a precision approach runway and where local conditions require an anemometer to be located inside the strip, the anemometer need not penetrate the inner transitional surface and the obstacle free zone. Consideration should be given to using frangible approach lighting towers for the anemometer masts.

Ceilometers

2.1.13 Observations of height of cloud base required for landing operations should be representative of the approach area, but in the case of precision approach runways, it should be representative of the middle marker site of the instrument landing systems. Measurement of the height of cloud base for precision approach runways should be made automatically by a ceilometer located near the middle marker. Where for any reason this is not possible, the ceilometer should be located within the runway strip but, except in very exceptional local circumstances, it need not penetrate the obstacle free zone. Where a ceilometer is used on non-precision or non-instrument approach runways, representative observations of height of cloud base can normally be obtained by locating the instrument outside the strip. The ceilometer rarely exceeds 1.5 m in height and usually comprises transmitter and receiver units.

Transmissometers

2.1.14 Transmissometers normally comprise transmitter and receiver units mounted on pylons approximately 1.5 m to 4.5 m high and separated along a baseline of 10 m to 200 m. Up to three sets of units may be required per runway. The transmissometer units should be located no farther than 120 m from the runway centre line. This means that transmissometers must be located within the runway strip. However, it would only be in very exceptional local circumstances that they would need to be located less than 60 m from the runway centre line and thus penetrate the obstacle free zone.

Fencing

2.1.15 Fencing should be provided on an aerodrome to deter the inadvertent or premeditated access of an unauthorized person onto a non-public area of the aerodrome. Fencing should also be provided to prevent the entrance into the movement area by animals large enough to be a hazard to aircraft. In general, the fence should be sited as far away from the runway and taxiway centre lines as practicable.

2.1.16 The fence should be provided with gates to allow for vehicle access to the movement area and for convenient access to areas outside the airport boundary by rescue and fire fighting vehicles. Gates, in particular heavy, remote-controlled gates, should be positioned outside of operational areas and as far away as possible from the runway or its extended centre line to minimize the structural damage to an aeroplane in the event of it colliding with a fence or its gates. Furthermore, so-called “crash gates” should be used to provide rescue and fire fighting vehicles easy access to areas outside the airport boundary.

2.2 PREFERRED SITING OF EQUIPMENT COMPONENTS

2.2.1 In cases where frangible design of equipment would be impracticable or would jeopardize the operational performance to stipulated requirements, the object should be relocated or otherwise positioned so as to not present a hazard to aircraft.

2.2.2 In systems design, consideration should be given to the possibility of arranging components in such a way as to limit the number and/or mass of obstacles on those areas that must be maintained free of all objects, except for frangible equipment and installations required for air navigation purposes (1.3.3 and 1.3.4 refer).

2.2.3 A review of relevant accident data reveals that a majority of the accidents in the overrun area occur within a distance of 300 m from the runway end. All equipment located within this area should, therefore, be of low mass and frangible. Where practicable, all equipment located beyond a distance of 300 m from the runway end should be of low mass and frangible. The available accident data also indicate that a majority of accidents occur where the aeroplane comes to rest within the graded portion of the runway strip. All equipment located within this portion of the strip should, therefore, be of low mass and frangible. Where practicable, all equipment located within the non-graded portion of the runway strip should be of low mass and frangible.

2.2.4 Where the function of equipment requires siting in an area that presents a hazard to aircraft, those components which can be moved outside the hazard area should be moved.

2.2.5 Where collocation is essential, an effort should be made to place components below the surface of the ground, where practicable.

2.2.6 Due to its heavy mass, the transmitter housing for ILS installations cannot be made frangible. Therefore, when planning for the installation of an ILS, the location of the transmitter housing for the localizer as well as for the glide path should be carefully considered. In no instance should the transmitter housing for the ILS localizer be located within the runway end safety area (or the extension thereof within a distance of 300 m from the runway end). Where practicable, the transmitter housing for the ILS glide path should be located outside the runway strip. In any event, the lateral displacement of the transmitter housing for the ILS glide path should not be less than 120 m with respect to the runway centre line.

2.2.7 MLS installations, including both the currently designed azimuth antenna and the elevation antenna are heavy equipment and cannot be made frangible. Therefore, these installations should be positioned so as to present the least hazard to aircraft. The MLS azimuth antenna should be located as far away as practicable from the runway end and, in any event, not closer than 300 m. Where practicable, the MLS elevation antenna should be located outside the runway strip.

2.2.8 Existing structures located within a distance of 300 m from the runway end not meeting the frangibility requirement, such as an existing non-frangible ILS localizer antenna array, should be replaced by a frangible structure or relocated beyond a distance of 300 m from the runway end. Similarly, structures located within the graded portion of the runway strip not meeting the frangibility requirement, such as an existing non-frangible ILS glide path antenna, should be replaced by a frangible structure, if practicable, and relocated within the non-graded portion of the runway strip. In this context, it should be noted that, generally, the lateral displacement of the ILS glide path antenna system should not be less than 120 m with respect to the runway centre line (2.1.8 refers).

Chapter 3

GENERAL DESIGN CONSIDERATIONS

3.1 OPERATIONAL REQUIREMENTS

3.1.1 It is normal for a frangible structure to deflect when exposed to environmental loads. However, it is important that deflection of the structure remain within limits so as not to affect the signal quality of the aid which the structure supports. To this end, 3.1.2 to 3.1.10 contain guidance on permissible deflection limits, i.e. deflection tolerances in respect of aids that are installed on tall poles or structures.

Approach lighting systems

3.1.2 When subjected to the envisaged environmental loads, the deflection of the structure should be such that the deflection of the light beam does not exceed ±2 degrees in the vertical axis and ±5 degrees in the horizontal axis.

Wind direction indicators

3.1.3 It is unnecessary to establish deflection tolerances in respect of this aid.

ILS localizer

3.1.4 When establishing deflection tolerances for the structure, the applicable system monitoring limits for each installation and facility performance category of operations should be taken into account.

ILS glide path

3.1.5 When establishing deflection tolerances for the structure, the applicable system-monitoring limits for each installation and facility performance category of operations should be taken into account.

MLS approach azimuth equipment

3.1.6 When establishing deflection tolerances for the equipment, the recommended permissible operating tolerance for beam accuracy should be taken into account.

MLS approach elevation equipment

3.1.7 When establishing deflection tolerances for the equipment, the recommended permissible operating tolerance for beam accuracy should be taken into account.

Note.— For further guidance on deflection tolerances discussed in 3.1.4 to 3.1.7, please refer to Annex 10, Volume I.

Anemometers

3.1.8 This equipment comprises a wind speed sensor and a direction sensor, usually collocated on the same mast. The mast should be subject to minimum vertical deflections so as to ensure that the sensors are always in equilibrium. This is necessary for the wind speed sensor (or propeller) to ensure that the response time is not adversely affected, and for the direction sensor (wind vane) to ensure that it does not have a preferred null position but has a single equilibrium position with respect to each wind direction.

Ceilometers

3.1.9 The structure has to be sufficiently stable in order to provide for measurement accuracy but less so than for transmissometers.

Transmissometers

3.1.10 Precise alignment of the transmitter and receiver are required in order not to compromise measurements. In view of this, the structure has to be sufficiently stable with minimal deflection in order to provide for measurement accuracy when subjected to envisaged environmental loads.

Fencing

3.1.11 The fence and its gates have to be sufficiently stable to serve the purpose and cannot be made frangible without detrimental effects to their intended function. However, the structure should be segmented and the design such that the failure mode of the structure would be “windowing” in the event of an aeroplane colliding with the fence.

3.1.12 Notwithstanding the above, a lightweight frangible fence should be installed when located between frangible approach lighting towers or when located to protect the ILS critical and sensitive areas against unlawful interference.

3.2 ENVIRONMENTAL SERVICE CONDITIONS

3.2.1 Although required to be of a frangible design to minimize hazard to aircraft in the event of impact, the object must also be capable of withstanding the environmental conditions to which it may be exposed during normal service. The following identifies several conditions that should be addressed by the designer. Specifics on these as well as other conditions can be found in the pertinent documents of the authority having jurisdiction.

Wind loading

3.2.2 The object should be sufficiently strong and rigid to meet the operational requirements of its normal service at the specified level of wind speed (e.g. 140 km/h (75 kt) with 12.5 mm of ice cover). In addition, the object should be capable of surviving a higher level of wind speed (e.g. 210 km/h (113 kt)). In designing, the wind loading should be based upon that historical projection (e.g. 50-year mean recurrence interval).

Jet blast

3.2.3 Loading generated by jet engine blast should not cause failure or permanent deformation. The exhaust contours of the design aircraft should be applied. The actual loading depends on the distance and orientation of the object from this aircraft.

Vibration

3.2.4 The components of the structure, which form the supporting means for the object, should be designed so that no member or combination of members vibrates at or close to the resonating frequencies induced by the aerodynamic response to wind forces, jet blast, earthquakes, etc.

3.3 FRANGIBILITY REQUIREMENTS

3.3.1 Equipment and its supports, located in areas described in section 1.3, should be frangible in order to ensure that they will break, distort or yield in the event that they are accidentally impacted by an aircraft. The design materials selected should preclude any tendency for the components, including the electrical conductors, etc., to “wrap around” the colliding aircraft or any part of it.

3.3.2 A frangible structure should be designed to withstand the static and operational wind or jet blast loads with a suitable factor of safety but should break, distort or yield readily when subjected to the sudden collision forces of a 3 000-kg aircraft airborne and travelling at 140 km/h (75 kt) or moving on the ground at 50 km/h (27 kt).

3.3.3 The frangibility of the design should be proven either by means of full-scale tests, computer evaluations or by calculations based on comparison with similar already approved structures possibly supported by additional component tests.

Chapter 4

DESIGN FOR FRANGIBILITY

4.1 DESIGN PHILOSOPHY

4.1.1 Equipment (and its supports) located near runways and taxiways should be designed to be frangible in order to limit the hazard to aircraft accidentally impacting them from any direction either in flight or during ground manoeuvring. Impact may affect flight safety in three ways:

a) the aircraft may lose momentum;

b) the aircraft may change direction; and

c) the aircraft may suffer structural damage.

4.1.2 The amount of momentum lost is mathematically governed by the integral of force over time. This implies that both the magnitude of the impact load and its duration should be as minimal as possible.

4.1.3 The structural damage to the aircraft is related to the amount of energy it requires to move the obstacle, or part of it, out of the way and should therefore be limited. This energy can be broken down into the following components:

a) energy to activate break-away or failure mechanisms;

b) energy required for plastic and/or elastic deformation of the obstacle, or part of it; and

c) energy required to accelerate the obstacle, or part of it, up to at least the aircraft velocity.

4.1.4 The energy required to activate break-away or failure mechanisms depends on the efficiency of their design and on the number of mechanisms to be activated. The energy absorbed by plastic or elastic deformation of the structure is strongly dependent on the choice of material: the amount will be higher for ductile materials with high-yield strains. The (kinetic) energy required to accelerate the obstacle, or part of it, is dependent on the aircraft velocity, which is not a design variable, and on the mass to be accelerated. Therefore, the mass should be limited, for example, by using low-mass materials and/or by limiting the amount of structure to be accelerated, which can be accomplished by incorporating suitably located break-away or failure mechanisms in the structure.

4.1.5 The structural damage to the aircraft is also related to the contact area between aircraft and obstacle through which the energy transfer takes place. A larger contact area is shown to prevent obstacles cutting deeply into the aircraft structure. This has an implication on the structural geometry of the obstacle.

4.2 FAILURE MODE

4.2.1 In order to meet the frangibility requirements, different failure mechanisms can be applied. For example, structures can be of modular design, which on impact “open a window” for the aircraft to pass through, or of a one-piece design, which on impact do not disintegrate but are entirely deflected away by the aircraft.

4.2.2 In the case of a modular design, the structure should contain break-away or failure mechanisms which, apart and together, require only a minimum amount of energy for their activation. This concept permits moving the least amount of mass out of the way of a colliding aircraft. The sequence of events is easier to predict as the structure behaves in a brittle way, disintegrating preferably at small deflections. It also reduces to a minimum the possibility of a “wrap-around” effect. However, in this case, detached fragments may be impacted by other parts of the aircraft passing the location of impact slightly later.

4.2.3 In the case of a one-piece design, the frangibility must be guaranteed by a complete failure of the structure, which is achieved by the random failure of structure members, instead of by failure of predetermined break-away or failure mechanisms. This implies that eventually the entire structure will be involved in the impact, resulting in a relatively high value of the kinetic energy required to move the structure out of the way. Therefore, this type of failure mechanism seems to be suitable only for lightly loaded structures, i.e. those meant to carry low-mass equipment. Moreover, due to the continuous nature of the structure, the sequence of events is difficult to predict and the tendency to “wrap around” the aircraft should be considered an additional hazard.

4.3 IMPACT LOAD

The impact load is a rapidly changing dynamic load of short duration. Typical loading and response times are in milliseconds. The impact load influences the frangibility performance in two ways. First, the maximum impact load may adversely affect the structural integrity of the aircraft. Second, the integral of the impact load over the duration of the impact leads to a change of momentum (including direction) of the aircraft.

4.4 ENERGY TRANSFER

4.4.1 During an impact, energy will be transferred from the aircraft to the obstacle. As the damage to the aircraft is proportional to the energy transferred, it should be limited. The energy required is estimated as follows:

a) The energy required to cause a break-away mechanism to fracture is determined in a laboratory on a component scale; this amount of energy must be multiplied by the number of mechanisms to be broken;

b) The energy required for plastic and/or elastic deformation is calculated or determined by simple tests; this energy is often negligible when stiff and brittle materials are applied in a modular design; and

c) The kinetic energy required for acceleration of the fragments, or the total structure in the case of a one-piece design, is calculated using the known mass and the representative aircraft velocity.

4.4.2 The estimation should be done for all different scenarios of an aircraft impacting the structure.

4.5 FRANGIBILITY CONCEPTS

General

4.5.1 The frangible structure should include concepts such as low-mass members, brittle or low-toughness members and connections, and/or suitable break-away mechanisms. Various design concepts exist, each with its own advantages and disadvantages. Designs may incorporate one or more concepts in order to ensure frangibility.

Frangible connections

4.5.2 In a frangible connection design, frangibility is incorporated in the connection, which carries the design load but fractures at impact. The structural member is not designed to break but rather to transfer the impact force to the connection. A stiff, lightweight member provides efficient load transfer to the connection and minimizes the energy absorbed from bending and mass acceleration. The connection should break at low energy levels, as determined by impact tests. Types of frangible connections include neck-down or fuse bolts, special material or alloy bolts, countersunk rivets or tear-through fasteners, and gusset plates with tear-out sections. Some of these are described as follows:

a) *Fuse bolts.* Failure of this type of connection is induced by providing a “stress raiser”, due to removal of material from the bolt shank. One method used to achieve this is to machine a groove to reduce the bolt diameter or to machine flats in the sides of the bolt, making it weaker in a specific direction. Shear strength is maintained and tensile strength is reduced by machining a hole through the bolt diameter and locating it out of the shear plane. Fuse bolts must be carefully installed to ensure they are not damaged or overstressed when tightened. The problem with fuse bolts is that the stress raiser may shorten the fatigue life of the bolt or may propagate under service loads and fail prematurely. Fuse bolts with machine grooves are commercially available. See Figure 4-1 for an example of the application of such fuse bolts.

b) *Special material bolts.* Use of fasteners manufactured from special materials eliminates the need for extensive machining or fabricating and allows the basic design to consist of conventional cost-effective techniques. The fasteners are sized to carry the design loads but are made from material with low-impact resistance. Materials such as steel, aluminium and plastic should be selected based on strength and minimum elongation to failure. Aluminium bolts of ANSI alloy designation 2024-T4 are recommended because they are as strong as stainless steel bolts but have only 10 per cent ultimate elongation compared to 50 per cent for stainless steel. Plastic bolts may have low elongation values, but their strength would have to be established by testing. Since frangibility is based on material selection, it is extremely important to purchase hardware with guaranteed compliance of physical properties.

c) *Tear-through fasteners.* Fasteners such as countersunk rivets can be used to sustain shear loads but tear through the base material if the impact force creates a tension load. The hole in the base material is accurately machined to grip a minimum amount of the area under the head of the fastener. The taper of the countersunk head also helps initiate the pull-through. This technique relies heavily on the manufacturing process and requires extensive quality inspection.

d) *Tear-out sections.* Connecting gusset plates can be designed with notches that will tear out with the member. In this type of connection the fastener does not break but instead is used to pull out a section of the gusset plate. Fatigue life and manufacturing quality are the primary design considerations.

Figure 4-1. Fuse bolt

Frangible members

4.5.3 In this design, the structural member is required to fail and not the end connection. The member should achieve a segmented-type separation along its length, thereby minimizing the amount of mass acceleration and reducing the potential of a wrap-around effect. Brittle materials such as plastic, fibreglass or other non-metals are more likely to be used than metals. The main advantage with frangible members is that impact forces do not have to be carried back to the connection in order to fail the section. This means that energy is not absorbed by bending the member as in a frangible connection design. The disadvantage is that special, non-metallic materials require extensive testing to establish properties to be used for deflection analysis of the structure. The analysis should also be confirmed by doing full-scale load tests on the structure. Non-metals must also contain ultra-violet inhibitors for protection against the environment.

4.5.4 Plastic extrusions or fibreglass-moulded sections are available in angular or tubular shapes. Members can also be specially fabricated to incorporate built-in break points. This is done by bonding one material to another at points along the length of the member. The bond line then becomes the fracture initiation point in the member.

Frangible mechanism

4.5.5 Frangibility can be incorporated into the support structure by means of a mechanism that slips, breaks or folds away on impact and removes the structural integrity of the support. A frangible mechanism can be designed to withstand high wind loads but remain very sensitive to impact loads. Frangible mechanisms tend to be directional in strength, i.e. they carry high tension and bending but very low shear.

4.5.6 Friction joints used as frangible mechanisms can supply high strength normal to the sliding surface but slip when the force is applied parallel to the sliding surface. In a support structure, impact forces are predominantly horizontal. Friction joints should be designed so that the slip plane is horizontal and complete failure occurs if impacted in any direction in that plane. This is achieved by using flange-type couplings on the ends of tower legs or interconnected tubes that slide apart on impact.

4.5.7 “Swing-away” support members can also be used as frangible mechanisms. These are incorporated into the structure to provide stability but if broken away on impact, leave the structure unstable and allow it to fracture. This type of design, however, may require large amounts of mass to be moved out of the way before failure.

4.5.8 Any design using frangible mechanisms has to ensure that no slippage or change in shape occurs from cyclic loading. For example, in a design using interconnecting tubes, vortex shedding on a tube caused by jet blast or wind could loosen or separate it from its counterpart.

4.6 BREAK-AWAY OR FAILURE MECHANISMS

The location of break-away or failure mechanisms should be such that disintegration results in components of predictable mass and size, which, in case of a secondary impact, do not present a greater hazard than they present as part of the undamaged structure. It is desirable that break-away or failure mechanisms be independent of the strength required for withstanding wind loads, ice loads and other environmental loads. In addition, the mechanism should not be subjected to premature fatigue failure.

4.7 MATERIAL SELECTION

4.7.1 Materials and configuration for frangible structures should be suitable for the intended use and should result in the lightest structure possible. Structures can be fabricated from metallic or non-metallic materials that are not adversely affected by outdoor environmental conditions. Material selected to meet frangibility requirements should be strong, lightweight and have a low modulus of toughness. Minimum weight is important to ensure that the least amount of energy is expended to accelerate the mass to the velocity of the impacting aircraft. In general terms, toughness is defined as the capacity of a material to resist fracture under dynamic loads. The modulus of toughness is the ultimate amount of energy by volume that a material will absorb and is determined by taking the area under the stress-strain diagram plotted to failure. Table 4-1 lists some common properties of metallic design materials.

4.7.2 Standard, commercially available materials provide the most cost-effective design. Non-metallic materials can be specially designed to provide excellent frangibility characteristics; however, their structural behaviour may be difficult to analyse because of uncertainty about their elastic modulus or material isotropy. All material must be able to withstand or be protected against environmental effects including weathering, solar radiation, temperature fluctuation, etc., typical of an outdoor environment.

Table 4-1. Properties of metallic design materials

Material	*Density (kg/m^3)*	*Yield strength (MPa)*	*Ultimate strength (MPa)*	*Ultimate elongation (mm/mm)*	*Toughness Modulus (MPa)*
Mild steel	7 850	240	413	0.35	114
Cast iron	7 190	41	138	0.05	4.5
Aluminium ANSI 6061-T6	2 710	276	310	0.12	35
Aluminium ANSI 2024-T4	2 710	275	275	0.10	35

4.8 ELECTRICAL COMPONENTS

4.8.1 Electronic equipment or components and supports should be designed to be frangible, while ensuring that the operational functions are not degraded. It is recommended that electronic equipment, etc., be positioned below ground level if possible.

4.8.2 The strength of electrical conductors incorporated in the design of frangible structures as well as the fire hazard presented by the arcing of disrupted conductors will have to be considered. It is recommended that conductors be designed such that they do not rupture but break at predetermined points within the limits for frangibility of the structure. This is accomplished by the provision of connectors that require a lower tensile force to separate than that required to rupture the conductor. In addition, the connectors should be protected by a break-away boot of a size commensurate with the voltage employed in order to contain any possible arcing at disconnection. Break-away connector assemblies are commercially available.

4.9 DESIGN CRITERIA FOR FRANGIBILITY

Elevated runway and taxiway edge lights

4.9.1 ***Wind.*** Light fixtures may be exposed to extreme wind loads and/or jet blast. Aerodromes should ensure that elevated runway and taxiway lights are capable of withstanding jet blast velocities from aircraft normally expected to operate. These are typically wind velocities of 480 km/h (260 kt) for all high- and medium-intensity lights and 240 km/h (130 kt) for all other elevated fixtures (low-intensity lights).

4.9.2 ***Yield device.*** Each elevated light fixture should have a yield point near the point or position where the light attaches to the base plate or mounting stake. The yield point should be no more than 38 mm above the ground surface and should give way before any other part of the fixture is damaged. The yield point should withstand a bending moment of 204 J without failure but should separate cleanly from the mounting system before the bending moment reaches 678 J. However, certain fixtures may bend instead of separating. In that case, the fixture should not bend more than 25 mm from vertical under the specified wind loading. Non-metallic yield devices should provide the specified performance over the designed temperature range with appropriate grounding capability for the attached fixture.

Taxi guidance signs

Note.— Taxi guidance signs include mandatory instruction signs, such as runway designation signs, category I, II and III holding position signs, runway-holding position signs, road-holding position signs and no entry signs as well as information signs, such as direction signs, location signs, runway exit signs, runway vacated signs and intersection take-off signs.

4.9.3 ***Environmental requirements.*** Signs, including all required components, should be designed for continuous outdoor use under the following conditions:

a) *Temperature.* An ambient temperature range from –20°C to +55°C or from –55°C to +55°C, as appropriate.

b) *Wind.* Exposure to wind and/or jet blast velocities of up to 480 km/h (260 kt). Reduced velocity requirements, e.g. 322 km/h (174 kt) or 240 km/h (130 kt), may be acceptable depending on expected sign location and airport use. Jet blast velocities vary depending on thrust used for take-off, taxi or break-away.

c) *Rain*. Exposure to driving rains.

d) *Snow and ice.* Exposure to snow and icing conditions, as appropriate.

e) *Salt.* Exposure to salt-laden atmospheres, as appropriate.

f) *Humidity.* Exposure to relative humidity from 5 to 95 per cent, as appropriate.

4.9.4 ***Sign construction.*** The signs should be constructed of lightweight, non-ferrous materials and should be designed for installation on a concrete pad or stakes. All required mounting or support hardware should be considered part of the sign for frangibility considerations.

4.9.5 ***Frangibility.*** Signs should be frangible. The overall mass of a sign including mounting fixture should be limited to 24.5 kg/m length and the total length of a sign should not exceed 3 m. In case the total message does not fit on a 3-m sign, two separate signs mounted side by side should be provided. Signs located near a runway or taxiway should be sufficiently low to allow clearance for propellers and engine pods of jet aircraft.

4.9.6 ***Mounting legs.*** Mounting legs for each sign should have frangible points located 50 mm or less above the concrete pad or stake. The frangible points should withstand the specified wind loading due to jet blasts but should break before an applied static load reaches a specified value (see 3.2.3). For a specified wind loading of 322 km/h (174 kt), breaking should occur before the applied static load reaches a value of 8.96 kPa.

4.9.7 ***Legend panels.*** Legend panels and panel supports should withstand, as a minimum, the pressure at which the frangible points break.

4.9.8 ***Break-away mechanism.*** Each break-away mechanism should be permanently marked with the manufacturer's name (which may be abbreviated) and the size of sign for which the mechanism is intended, as a minimum.

PAPI/APAPI and T-VASIS/AT-VASIS

4.9.9 ***Wind.*** PAPI/APAPI (abbreviated PAPI) and T-VASIS/AT-VASIS (abbreviated T-VASIS) may be exposed to extreme wind loads and/or jet blast. Aerodromes should ensure that these systems are capable of withstanding jet blast velocities from aircraft normally expected to operate. These are typically wind velocities of 480 km/h (260 kt) for aerodromes used by aircraft with high jet blast velocities and 240 km/h (130 kt) for other aerodromes.

4.9.10 ***Mounting provisions.*** The light units should be mounted as low as possible and should be frangible. In addition, they should have a minimum of three adjustable mounting legs, which should be adjustable to permit levelling. The legs should consist of mounting and adjusting hardware, a break-away mechanism, as required, as well as flanges suitable for mounting on a concrete pad. The adjusting hardware should be designed to prevent any displacement of the optical system due to vibration. Alternate mounting systems may be proposed where equivalent rigidity, frangibility and adjustability are provided.

Approach lighting systems

4.9.11 As defined in Annex 14, Volume I, Chapter 5, elevated approach lights and their supporting structures should be frangible except that, in that portion of the approach lighting system beyond 300 m from the threshold:

a) where the height of a supporting structure exceeds 12 m, the frangibility requirement should apply to the top 12 m only; and

b) where a supporting structure is surrounded by non-frangible objects, only that part of the structure that extends above the surrounding objects should be frangible.

4.9.12 A selection of commercially available frangible towers is shown in Figures 4-2 to 4-5. An approach lighting station of rigid design being replaced by new frangible structures is shown in Figure 4-6, and a fibreglass tubular pole on a rigid structure is shown in Figure 4-7.

4.9.13 An example of approach lighting towers where the supporting structures exceed 12 m is shown in Figure 4-8.

Supporting structures

4.9.14 ***Wind.*** The supporting structures should be designed to withstand wind and ice loading typical of the local conditions in accordance with national standards when installed with all lighting equipment attached. The structure should not have any permanent deformation as a result of the wind load.

4.9.15 The design wind pressure can be determined using the following formula:

$$P = 0.0000475 * V^2$$

where P = pressure in kPa; and
V = wind speed in km/h.

The design wind pressure is independent of the shape of the structure. The design wind pressure levels for winds and/or jet blasts of 480 km/h (260 kt), 322 km/h (174 kt) and 240 km/h (130 kt) are 11.52 kPa, 5.12 kPa and 2.88 kPa, respectively.

4.9.16 The total wind loading affecting a structure should be adjusted for the shape of the structure using a shape factor, as appropriate.

4.9.17 ***Jet blast.*** The typical location of elevated approach lights and their supporting structures is such that jet blast loads would not exceed the environmental loads. Aerodromes should assess the specific local need for lighting structures that may be affected by jet blast.

4.9.18 ***Deflection.*** The deflection of the light beam should be no more than ±2 degrees in the vertical axis and no more than ±5 degrees in the horizontal axis when the structure is subjected to a wind velocity of 100 km/h (54 kt) and coated with 12.5 mm of ice on all surfaces.

4.9.19 Any approach lighting structure required to be frangible should be designed to withstand the static and operational/survival wind loads with a suitable factor of safety but should break, distort or yield readily when subjected to the sudden collision forces of a 3 000-kg aircraft airborne and travelling in any direction at 140 km/h (75 kt). The structure must break, distort or yield without imposing maximum force or energy according to the requirements of this paragraph, as well as those of 4.9.20 to 4.9.23. After a collision, the structure should not become entangled with the aircraft in a manner that will prevent the aircraft from manoeuvring safely either in flight or on the ground. Approach lights and associated wiring supported by the structure should be considered part of the structure for frangibility purposes.

Figure 4-2. Approach lighting towers — fibreglass lattice structures

Figure 4-3. Approach lighting towers — fibreglass tubular poles

4.9.20 The support structure should not impose a force on the aircraft in excess of 45 kN. The maximum energy imparted to the aircraft as a result of the collision should not exceed 55 kJ over the contact period between the aircraft and the structure. To allow the aircraft to pass, the failure mode of the structure should be one of the following:

a) fracture;

b) windowing; or

c) bending.

4.9.21 The impacted structure should give way to passage of the aircraft in a manner such that the latter may still achieve a successful landing, take-off or missed approach.

4.9.22 All individual components of the structure released by the impact should be kept to as low a mass as possible in order to minimize any hazard to aircraft.

4.9.23 The light fitting and the supporting structure as a whole should be considered for establishing frangibility of the system. With regard to cabling, the designer should ensure that there are points of disconnection so that segmentation is not hindered, if this is the intended mode of failure.

Figure 4-4. Approach lighting towers — aluminium lattice structures

Figure 4-5. Close-up of an approach lighting tower — aluminium lattice structure

Figure 4-6. Approach lighting station of rigid design (left) being replaced by new frangible structures (right)

Figure 4-7. Fibreglass tubular pole on rigid structure

Figure 4-8. Fibreglass approach lighting towers on rigid supporting structures

ILS/MLS structures and other non-visual aids

4.9.24 ***Wind.*** Non-visual aids and their supporting structures should be designed to withstand wind and ice loading typical of the local conditions in accordance with national standards. The structures should not have any permanent deformation as a result of the wind load.

4.9.25 ***Jet blast.*** The typical location of non-visual aids, such as an ILS and MLS equipment (300 m beyond the runway end or a lateral displacement of 120 m with respect to the runway centre line), is such that jet blast loads do not exceed the environmental loads. Should site requirements be such that equipment must be located closer to the runway, then jet blast effects must be evaluated.

4.9.26 ***Deflection.*** Deflection tolerances for ILS and MLS installations should be in accordance with the applicable system-monitoring limits for each facility performance category of operation. For further guidance, please refer to Annex 10, Volume I.

4.9.27 ***Frangibility.*** Any equipment or installation required for air navigation purposes which must be located:

a) on a runway strip, a runway end safety area, a taxiway strip or within the distances specified in Annex 14, Volume I, Table 3-1; or

b) on a clearway and which would endanger an aircraft in the air;

should be frangible and mounted as low as possible.

4.9.28 Any equipment or installation required for air navigation purposes which must be located on or near a strip of a precision approach runway category I, II or III and which:

a) is situated within 240 m from the end of the strip and within:

   1) 60 m of the extended runway centre line where the code number is 3 or 4; or

   2) 45 m of the extended runway centre line where the code number is 1 or 2; or

b) penetrates the inner approach surface, the inner transitional surface or the balked landing surface;

should be frangible and mounted as low as possible.

4.9.29 Furthermore, any equipment or installation required for air navigation purposes which is an obstacle of operational significance in accordance with Annex 14, Volume I, 4.2.4, 4.2.11, 4.2.20 or 4.2.27, should be frangible and mounted as low as possible.

4.9.30 Non-visual aids required to be frangible should be designed to withstand the static and operational/survival wind loads with a suitable factor of safety but should break, distort or yield readily when subjected to the sudden collision forces of a 3 000-kg aircraft airborne and travelling at 140 km/h (75 kt), as detailed in 4.9.19 to 4.9.23.

4.9.31 ILS/MLS installations present special cases. The requirements of 4.9.24 to 4.9.30 are applicable for ILS/MLS structures, but the design criteria associated with a 3 000-kg aeroplane cannot be applied in all instances for the following reasons:

a) The design criteria associated with a 3 000-kg aeroplane should be retained for the ILS localizer. Current designs prove that light-weight structures for such installations can be applied. The possibility of using modular designs, thereby limiting the total mass, should also be considered. The validation of energy assumptions and development of values for mass limitation require special study.

b) Considering the unique nature of the tower structure supporting the ILS glide path antenna, frangibility criteria have not yet been developed.

c) It has been recognized that, because of its heavy mass, the transmitter housing for ILS installations cannot be made frangible. Therefore, when planning for the installation of an ILS, the location of the transmitter housing for the localizer as well as for the glide path should be carefully considered. In no instance should the transmitter housing for the ILS localizer be located within the runway end safety area (or the extension thereof within a distance of 300 m from the runway end). In any event, the lateral displacement of the transmitter housing for the ILS glide path should not be less than 120 m with respect to the runway centre line. Where practicable, the transmitter housing for the ILS glide path should be located outside the runway strip.

d) It has also been recognized that the design criteria associated with a 3 000-kg aeroplane cannot be applied to MLS installations. Both the MLS azimuth antenna and the MLS elevation antenna of current design are heavy equipment and cannot be made frangible. Therefore, these installations should be positioned so as to present the least hazard to aircraft. The MLS azimuth antenna should be located as far away as practicable from the runway end and, in any event, not closer than 300 m. Where practicable, the MLS elevation antenna should be located outside the runway strip.

e) The total mass of MLS azimuth antennas currently available could be from 200 kg to 700 kg. Earlier designs have proven to be even heavier. Therefore, the mass of the antenna itself would be prohibitive, and the issue of frangibility of its support would be irrelevant if the design criteria for frangibility were the same as those applied for approach lighting towers and similar lightweight structures. As a consequence, if the MLS azimuth antenna and its supports as well as other heavy systems were to be regulated in terms of frangibility, the design criteria need to be redefined based on more realistic assumptions.

Chapter 5

TESTING FOR FRANGIBILITY

5.1 GENERAL

5.1.1 The primary purpose of this section is to foster uniform procedures of testing by which the concerned authority may determine the acceptability of designs as being in conformance with frangibility requirements.

5.1.2 The frangibility of any aid should always be proven before the aid is considered for installation. High-speed, full-scale testing is a proven method for verification of frangibility. Results of numerical simulation show this approach to be capable of demonstrating frangibility. However, as for any numerical simulation methods, the model and simulation approach used must be validated for this purpose by comparison with representative test data. Numerical simulation methods are discussed in Chapter 6.

5.1.3 Due to the number of aids involved and the variation of site conditions, the tests detailed herein are not the limit of tests that might be undertaken but are given as general guidance to the extent practicable.

5.1.4 Static tests, as opposed to dynamic tests, are considered adequate for verification of frangibility of visual aids of low mass having an overall height equal to or less than 1.2 m, such as elevated runway and taxiway lights, taxiing guidance signs and visual approach slope indicator systems.

5.1.5 Dynamic tests are recommended for verification of frangibility of navigational aids having an overall height in excess of 1.2 m and located in positions where they are likely to be impacted by an aircraft in flight. Such aids are approach lighting towers, wind direction indicators, transmissometers, ILS localizer and glide path antennas and MLS approach azimuth and elevation equipment. The ILS glide path antenna and the MLS approach azimuth and elevation equipment provide a unique situation due to the size and mass of the instrument and support structure. While frangibility requirements should be applied to this equipment in general, these requirements may be too restrictive for such large structures.

5.1.6 These testing procedures focus on full-scale testing of representative structures. These structures should be manufactured using production techniques and equipment for the service structure to be installed. For new products that require testing before committing to production tooling or procedures, initial testing may be done on a pre-production unit to gain confidence in the design approach, but final qualification of the design must be performed on a production quality unit.

5.2 TESTING PROCEDURES

Elevated runway and taxiway edge lights

5.2.1 ***Yield device.*** The manufacturer should furnish test reports showing that the yield device meets the requirements of 4.9.2. All tests should be performed with the light unit fully assembled at nominal height and mounted to a rigidly secured base plate. The load should be applied to the body at a point just below the lens, no faster than 220 N per minute until the minimum bending moment described in 4.9.2 is achieved. After it is determined that the light unit sustains this load without damage, the loading should continue at the same rate until yielding at the yield point occurs. For “pop-out” or other friction-fit devices, the test should be repeated ten times on the same device to check for loosening of the attachment. The test should be repeated on a total of five frangible fittings. Tests for non-metallic yield devices should also be conducted at –55°C and +55°C (±15°). Failure of any of the devices to meet the requirements of 4.9.2 or damage to any part of the light unit before the yield device gives should be cause for rejection. For friction-fit devices, the manufacturer should provide data on how many “pop-outs” may be expected before the device fractures below the minimum yield value.

Taxiing guidance signs

5.2.2 A sign should be tested to verify its performance to meet the requirements of frangibility while withstanding wind loadings specified in 4.9.3 b).

5.2.3 ***Wind load and frangibility test.*** The test should be performed as follows:

a) The sign should be tested for its ability to withstand the specified wind loading. The test should be performed with the sign completely assembled and mounted by the base assembly. If wind loading is applied with the sign mounted on a vertical surface, the weight of the sign should be included as part of the total applied weight. The test should be designed to ensure that the legend panel receives the full load. Spring-mounted signs designed to swing should be locked to prevent movement during the test. A static load should be applied uniformly over the entire surface of the legend panel for a period of ten minutes. The sign should not break at the frangible points nor suffer permanent distortion. For a specified wind loading of 322 km/h (174 kt), the applied static load should be 6.21 kPa.

b) After satisfying the test specified in 5.2.3 a), any sign that meets the maximum mass requirement indicated in 4.9.5 should be considered frangible. Any sign that does not meet the mass requirement should be further tested in accordance with 5.2.3 c).

c) The static load over the legend panel should then be increased until the sign breaks at the frangible points. The breaking should occur before the applied static load reaches a specified value. Next, the legend panel and panel supports should be inspected for evidence of damage. Any breakage or deformation should be cause for rejection. For a specified wind loading of 322 km/h (174 kt), the breaking should occur before the applied static load reaches a value of 8.96 kPa.

5.2.4 Spring-mounted signs may be alternately tested in accordance with the procedure described in 5.2.5.

5.2.5 ***Spring-mounted signs.*** With the legend panel protected, the sign should be tested for frangibility according to 5.2.3. The sign should then be unlocked and subjected to Pbreak (the pressure at which the frangible points break). The sign swing angle, 0, caused by the pressure, Pbreak, should be measured. The pressure, Pswing, should then be computed as follows: Pswing = Pbreak * cosine 0. With the sign relocked and the legend panel protection removed, the Pswing should be applied uniformly over the entire surface of the legend panel for one minute. The legend panel and panel supports should then be inspected for evidence of damage. Any breakage or deformation should be cause for rejection.

PAPI/APAPI and T-VASIS/AT-VASIS

5.2.6 ***Wind load.*** The manufacturer should demonstrate by wind tunnel tests or static load that the system will withstand the wind load specified in 4.9.9 from any direction in azimuth without displacing the optical pattern more than allowed in the rigidity test.

5.2.7 ***Frangibility test.*** The manufacturer should demonstrate the frangibility of the mounting legs.

Approach lighting towers and similar structures

5.2.8 ***Frangibility test.*** Navigational aids such as approach lighting towers having an overall height in excess of 1.2 m and located in positions where they are likely to be impacted by an aircraft in flight should be verified for frangibility by dynamic testing. It is desirable that testing be carried out in a manner such that the conditions under which the structure might actually be impacted are simulated on a worst-case basis. To this end, tests should be conducted with a vehicle-driven impactor with a representative mass equivalent to the weight of the intended aid mounted on the top of the tower. An example of a general set-up for testing of approach lighting towers is shown in Figure 5-1.

5.2.9 ***Reference impactor.*** A large number of impact tests for approach lighting towers have been conducted. Reports on these tests are included in the References at the end of this manual. Various types of impactor designs have been investigated through impacts with towers of different designs, such as impactors duplicating, as close as possible, the structure, strength and stiffness of a wing of a 3 000-kg aeroplane, as well as rigid impactors made from thick-wall steel tubing. High-speed tests at 140 km/h (75 kt) representing an impact during flight, intermediate-speed tests at 80 km/h (43 kt) and low-speed tests at 50 km/h (30 kt) representing aircraft taxiing on the ground have been conducted.

5.2.10 Tests have also been conducted to determine the effect of impactor rigidity on the key parameters of frangibility, such as maximum impact force, time of contact and maximum energy change over the contact time. The analysis of results shows that a rigid impactor yields a conservative estimate of the maximum force on impact and an equivalent energy over the contact period. Contact time is also similar for all impactor types and tower designs, i.e. 100 milliseconds. One key observation is that the tower does not remain in contact with the impactor indefinitely. Separation of the tower in a short period of time enables the aeroplane to carry on without the possibility of a secondary impact.

5.2.11 As a result of these analyses, the recommended impactor design is a “rigid” semicircular tube, 1 000 mm or five times the maximum cross-sectional dimension of the tower, whichever is the greater. The outer diameter of the tube should be approximately 250 mm and the wall thickness should be sufficiently thick to represent a rigid body but not less than 25 mm. The material used for the impactor should be steel. The surface finish should be generally smooth and no coating or finish is required.

5.2.12 Use of a rigid impactor is recommended in order to obtain representative or conservative data during full-scale, high-speed impact testing. A rigid impactor is less expensive to fabricate, does not require the sophistication of wing section construction, nor the precision related to the materials and/or method of fabrication. In addition, it can be reused without modification for repeated tests, since it is unlikely to experience the plastic deformation and skin tearing of a representative wing section.

5.2.13 The rigid impactor must be firmly and rigidly attached to the test vehicle to ensure that the interface provided during impact is that of a rigid section. Load cells should be incorporated between the impactor and the interface on the vehicle, as close as possible to the mounting location to record the time history and the force of impact. A sufficient number of load cells should be employed to ensure that any moments generated in the impactor due to impacts off its centre line or reaction forces and moments of the

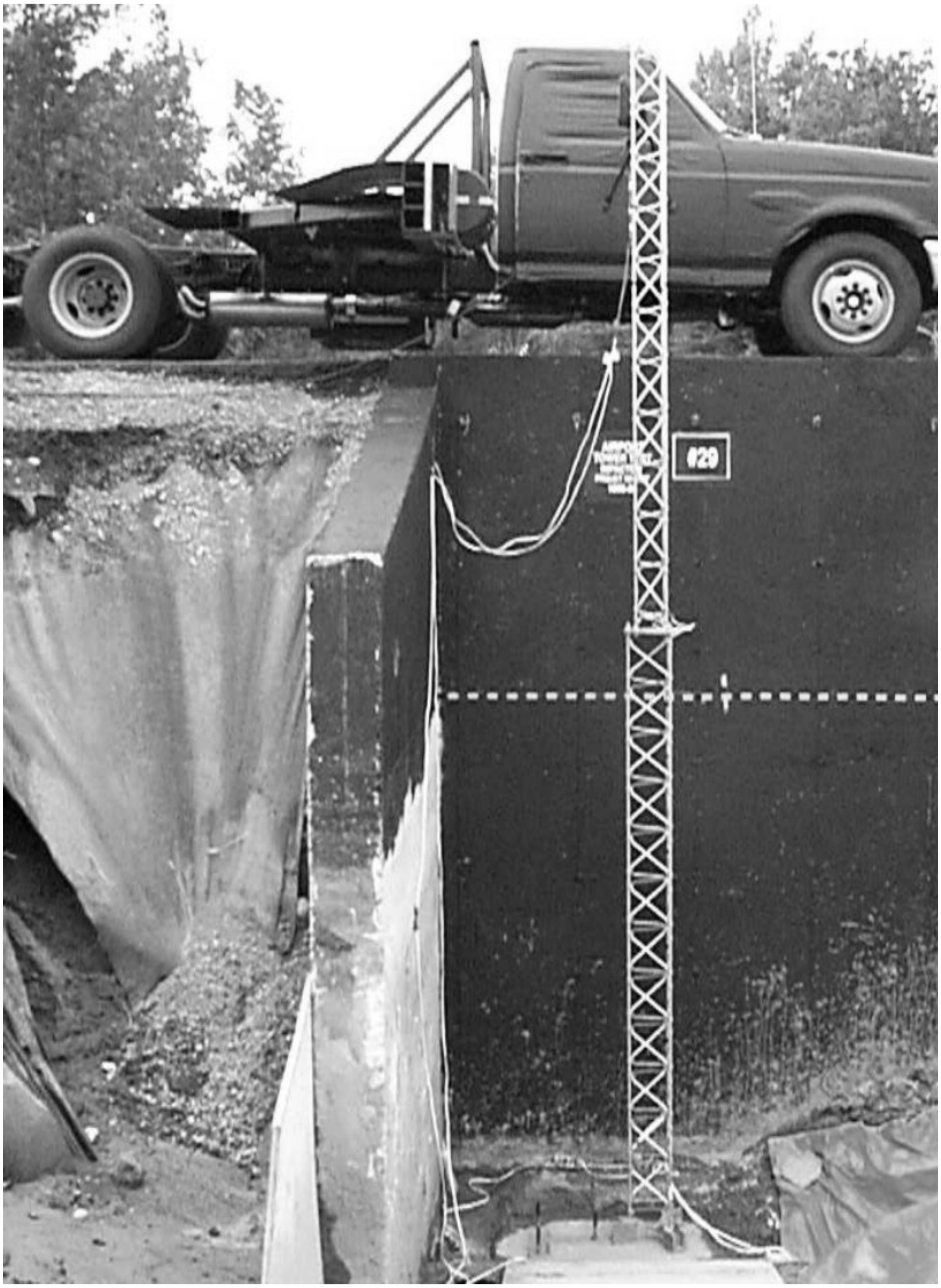


Figure 5-1. Example of a general set-up for testing approach lighting towers with a vehicle-driven impactor

tower on its mounting fixture are recorded and evaluated. Energy over the contact period is calculated by integration of the impact force with respect to distance.

5.2.14 ***Test procedure.*** The test should be conducted at a speed of 140 km/h (75 kt). The impactor should be mounted on the vehicle so that it strikes the structure at a point approximately 4 m above ground level or 1 m below the top of the structure, whichever is higher. A representative mass equivalent to the weight of the intended aid should be mounted on the top of the tower. All required wiring and cabling for the aid should also be mounted and secured. The overall tower height should be measured from ground level and should include both the support structure and the representative mass.

5.2.15 The impact should be recorded by a high-speed camera or video so as to reveal the mode of failure. Due to the short time of impact, it is impossible to visually monitor the impact sequence and the deformation. Also, post-impact deformation is very different from that at impact.

5.2.16 Impact speed should remain constant during impact and should be accurately and directly recorded from the moving vehicle at the time of impact.

5.2.17 Sufficient recording capability and speed should be used to accurately record the data from the load cells during impact tests. It is recommended that a recording speed of at least 10 kHz be used to capture the maximum impact force that occurs within 2 to 5 milliseconds.

5.2.18 ***Acceptance/rejection criteria.*** An approach lighting tower should be considered “frangible” if it meets the requirements of 4.9.19 to 4.9.23.

5.2.19 Other criteria, based upon visual inspection, should also be used when determining acceptance or rejection:

a) In the case of towers that may be impacted by airborne aircraft, it is desirable to not only minimize the amount of damage to the aircraft but also to not significantly impede the flight trajectory. The impacted tower should give way to the passage of the aircraft so that it may still achieve a successful landing or continue the take-off procedure. The portion of the tower above the point of impact should not grasp the aircraft wing while the lower portion remains attached to the foundation, thus inordinately altering the direction of aircraft. Towers that “wrap-around” the aircraft’s wing do not necessarily present a hazard if there is segmentation, or its bottom portion releases from the foundation and is carried by the aircraft. The tower’s response to impact is affected not only by the structure but also by other components that are part of the installation. In the case of cabling, the designer should ensure that there are points of disconnection so that segmentation is not hindered.

b) Upon impact, the tower may fragment into several components. The mass of these components and their manner of release should not cause a secondary hazard to the aircraft (e.g. to enter through the windscreen, fuselage, tail surfaces).

c) In the case of structures that may be impacted by aircraft on the ground, more damage is acceptable than that allowed for objects impacted by airborne aircraft. Since the aircraft is already on the ground, the primary objective is to avoid injury or loss of life.

Wind direction indicators/transmissometers/ forward-scatter meters

5.2.20 Support structures for wind direction indicators, transmissometers and forward-scatter meters should be tested for frangibility in accordance with procedures for approach lighting towers.

ILS/MLS structures

5.2.21 No full-scale testing has been undertaken so far to establish design criteria and testing procedures for frangibility of ILS/MLS structures. Nevertheless, it is planned to provide numerous new ILS installations as well as a limited number of new MLS installations (particularly in western Europe) in the next 10 to 15 years. Due to their location in the overrun/undershoot area, the ILS localizer and the MLS azimuth antenna constitute a greater hazard to aircraft operations than the ILS glide path antenna and the MLS elevation antenna located on the runway strip at a certain distance from the centre line (normally 120 m). The requirement for full-scale, high-speed testing using a rigid impactor was developed for lightweight tower structures with a minimal top mass but is impracticable to apply to different types of structures or to towers with a heavier top mass. Accordingly, an alternative to full-scale testing for evaluation of frangibility of such structures is required.

5.2.22 Notwithstanding the above, the design criteria associated with a 3 000-kg aeroplane should be retained for the ILS localizer. As indicated in 4.9.31, current designs prove that light-weight structures for such installations can be applied. The possibility of using modular designs, thereby limiting the total mass, should also be considered. The validation of energy assumptions and development of values for mass limitation require special study.

5.2.23 It is not envisaged that full-scale tests of ILS/MLS installations and their supports will take place in the future. Therefore, until computer models are further developed, verification procedures and acceptance criteria for such installations cannot be specified. As a result, it is recommended that in cases where frangible design of equipment is impracticable or jeopardizes the operational performance to stipulated requirements, the equipment should be relocated or otherwise positioned so as not to present a hazard to aircraft. Generally, where relocation is impracticable, installations should be made as lightweight as possible. In particular, consideration should be given to the possibility of arranging components in order to limit the number and/or mass of obstacles on those areas that must be maintained free of all but frangible equipment and installations required for air navigation.

5.3 TESTS BY MANUFACTURERS AND TESTING ORGANIZATIONS

5.3.1 Some of the full-scale testing described in this chapter is complex and requires a substantial investment for set-up and instrumentation. Nevertheless, it is considered that these tests be carried out by the manufacturers who have responsibility for design-testing of their products.

5.3.2 Full-scale testing as described in 5.2.8 to 5.2.17 for approach lighting towers is within the capability of recognized independent testing organizations.

Chapter 6

NUMERICAL SIMULATION METHODS FOR EVALUATING FRANGIBILITY

6.1 GENERAL

6.1.1 The cost and complexity of performing simplified field tests for frangibility remain high and time-consuming. Furthermore, it is not possible to test all combinations of speed, direction, altitude, etc., since there are numerous designs of both navigational aid structures and aircraft. Finally, it is preferable to obtain a validation technique that can be used to address all the issues, changes and developments that may occur in the future. Therefore, alternative methods to evaluate the frangibility of airport structures may be used.

6.1.2 Modern computational capability and power has advanced structural design and analysis through the use of software capable of predicting the response of a structure with great accuracy. These approaches are generally categorized as either finite element or finite difference approaches. Moreover, these computer programmes were enhanced to include transient dynamic analyses during an impact situation, in addition to enabling detailed analysis of very complex and detailed structures. Several major computer programmes were developed recently and have provided excellent results. Confidence in these approaches continues to grow to the point that major design efforts including large transport aircraft and automotive vehicles now rely on analysis for an increasing amount of design verification. Unfortunately, each software programme for structural analysis has unique features that are emphasized in its performance at the expense of others. Also, it is generally accepted that such analytical models should still be verified through a series of representative field tests.

6.2 ANALYSES

6.2.1 Computational analyses are currently under way to aid in the verification of frangibility of airport structures. The goal of this work is to develop and demonstrate the capability to accurately model a typical airport structure by comparing predicted results to full-scale impact test data. Once verified, these models can be used to investigate other configurations and parameters of impact to assess the performance of the structure. The models can also be used to interpolate test data for new or varied conditions and to extrapolate it over a short range to help predict the behaviour and performance of the structures. The ultimate goal is to be able to develop the capability and confidence to model new and different situations and structures through analysis. However, this goal is not likely to become available in the near future, although the initial goal of interpolation and minor extrapolation is viable.

6.2.2 ***Detailed modelling.*** One approach to analytical modelling of the impact uses successful, commercially available finite element analysis (FEA) programmes. These programmes are sold and distributed commercially with specific features such as pre- and post-processors to facilitate model generation and data analysis. Explicit, non-linear FEA programmes are used for impact analysis and large deformation because of their ability to continue analysis after predicted “fracture” of elements that comprise the model. Such models typically involve many standard members of different shapes, degrees of freedom and complexity. Non-linear material properties, transient dynamic analysis, contact elements and discontinuous elements are some of the features that enable modelling of real situations. Furthermore, these programmes enable modelling of the complex interaction that occurs at the contact interface as well as inside the model of the structure. Examples of three-dimensional FEA models of approach lighting towers are shown in Figure 6-1.

6.2.3 ***Intermediate modelling.*** FEA offers detailed design and design condition orientation, local interaction behaviour, design accuracy and specific component application. Another approach to analytical modelling is the intermediate or hybrid modelling, which offers a practical, cost-efficient analysis technique more closely associated with preliminary design, global analysis and parametric trade-off studies. This approach is ideally suited as a tool to evaluate potential design concepts and overall behaviour with a view to improving frangibility of structures. The hybrid programme allows the use of available test or other data as input along with the internal calculation of structural parameters. The hybrid programme is also compatible for coordinating with FEA model data. The choice of available hybrid programmes is more limited than FEA programmes.

6.3 FINITE ELEMENT ANALYSIS (FEA) APPROACH

6.3.1 Detailed numerical modelling using FEA has involved simulation of results of high-speed, full-scale impact tests at speeds of 140 km/h (75 kt), 80 km/h (43 kt) and 50 km/h (27 kt). Details of the geometrical, mechanical and material parameters of the structures used in these tests were available for the model construction. Experimental results from strain gages and load cells were used and compared to the numerically predicted values of force, strain and time. In addition, a high-speed video of the impact deformation was used to compare deflection modes and results.

6.3.2 To represent the tower, an elastic, plastic material model with the properties of aluminium was constructed from approximately 2 000 beam elements, each with six degrees of freedom at each node. These degrees of freedom include three translations and three rotations by node. The tower was impacted using a rigid model comprising about 600 solid elements with the material properties of steel. The interaction between disjoint parts was treated using contact elements. A contact force transducer was also defined to monitor the impact forces at the interface. A representation of the model is shown in Figure 6-1 b).

6.3.3 Results of the modelled impacts compare very favourably to those of full-scale, high-speed tests. Deformation of the analytical model in the FEA simulation is compared to that of a full-scale tower during impact (see Figures 6-2 and 6-3). Note that the mode and magnitude of deformation as well as the time in the simulation compare very closely to the test data. Failure modes of the tower are also predicted analytically.

6.3.4 Predicted impact force also compares very well to that measured in tests. Examples of the predicted data for force in the simulation compared to those of test data are shown in Figures 6-4 and 6-5.

6.3.5 The simulation work shows that transient dynamic analysis using a validated model with an explicit FEA programme has the capability to predict the full details of the impact process, including fracture and separation of the members.

6.4 HYBRID APPROACH

6.4.1 Intermediate numerical modelling using the hybrid approach can be used as a preliminary design tool to evaluate potential design concepts, overall behaviour and to improve frangibility of structures. This approach models large regions of the structure in a simplified manner and uses available test or analytical data, such as FEA, as input. Hybrid analysis is ideally suited for preliminary analysis wherein detailed design data is lacking and is highly adaptable to design parameter variation and trend studies by virtue of fast computational times.

6.4.2 Contrary to an FEA model, only a limited number of elements are necessary in the hybrid approach. The models used in the numerical analysis of lattice approach light masts typically consist of approximately 100 beam elements. The mechanical and failure properties of the beams are determined by component tests.

6.4.3 As in the case of FEA, the results obtained with the hybrid analysis model compare favourably with those obtained from full-scale tests. Figure 6-6 shows the overall deformation mode during the impact event predicted by the hybrid analysis model.

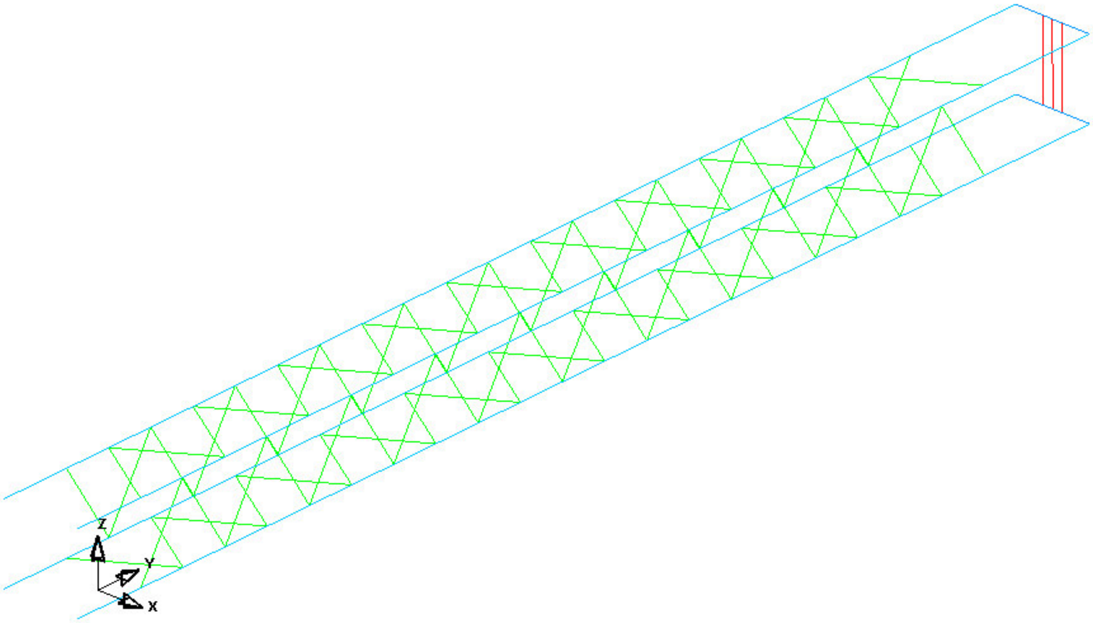
6.4.4 Besides the overall deformation mode, the maximum contact force and the energy absorbed during the impact event are also approximated within acceptable limits, as shown in Figures 6-7 and 6-8.

6.4.5 The time to run a hybrid analysis is typically several minutes.

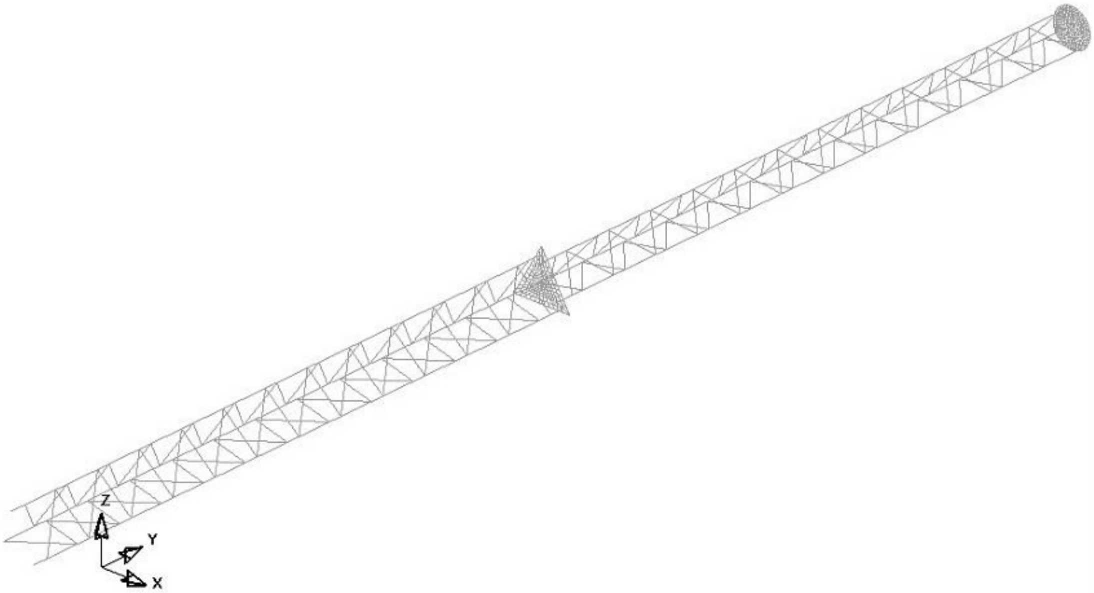
6.5 VERIFICATION BY COMPUTATIONAL ANALYSIS

6.5.1 The goal of work in computational analysis is to develop and demonstrate the ability to properly model impact and thereby predict results within a short time at reduced cost. As noted in 6.4.3, it is expected that this approach will support test results by providing additional information. This will provide a major enhancement to the ability to qualify structures with location differences such as mounting, height and changes in instrument. Such an approach would assist in verifying the frangibility of airport structures.

6.5.2 In general, the ability to model, simulate and predict structural dynamic transient performance of a structure requires a complex but commercially available software package and skilled modelling capability. However, once verification by analysis is validated and implemented, it is perceived that this capability will be useful in many situations and locations worldwide. The capability to perform these analyses is available through specified, independent testing organizations that have both the technical capability and experience in this area of structural impact.

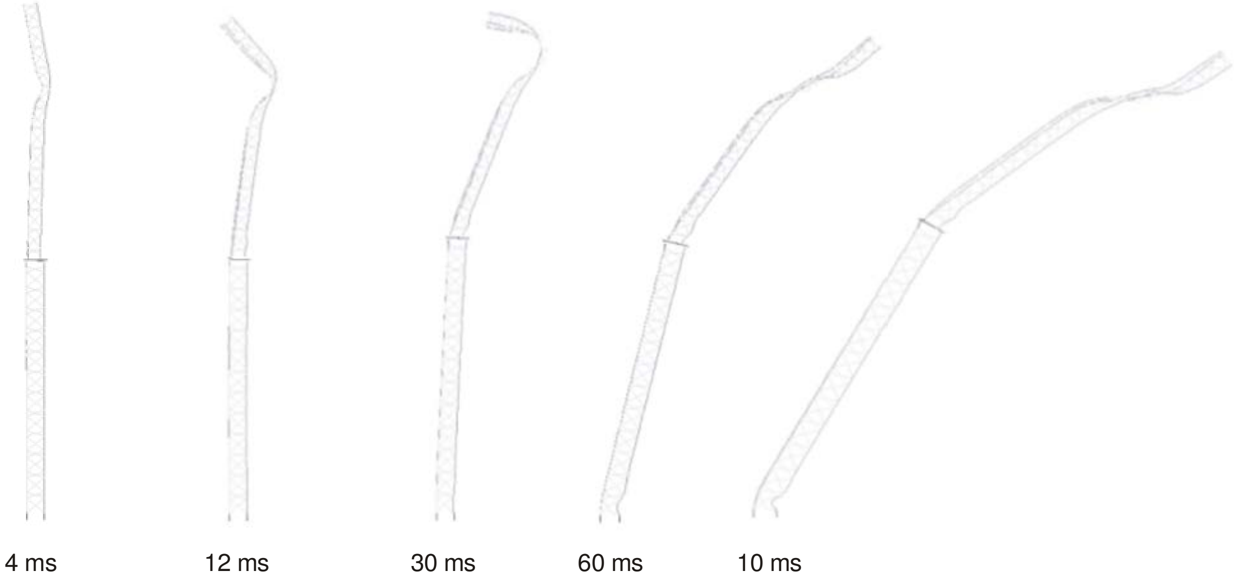


a) Approach lighting tower — fibreglass lattice structure

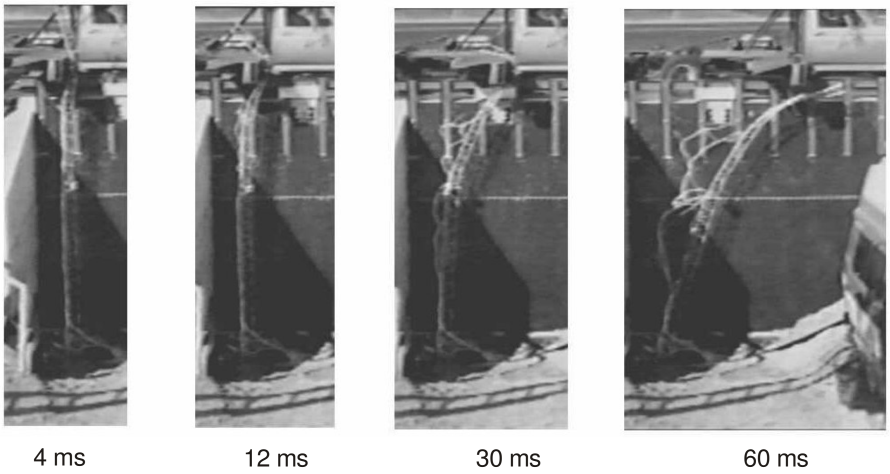


b) Approach lighting tower — aluminium lattice structure

Figure 6-1. Examples of three-dimensional finite element analysis (FEA) models of approach lighting towers



FEA simulation

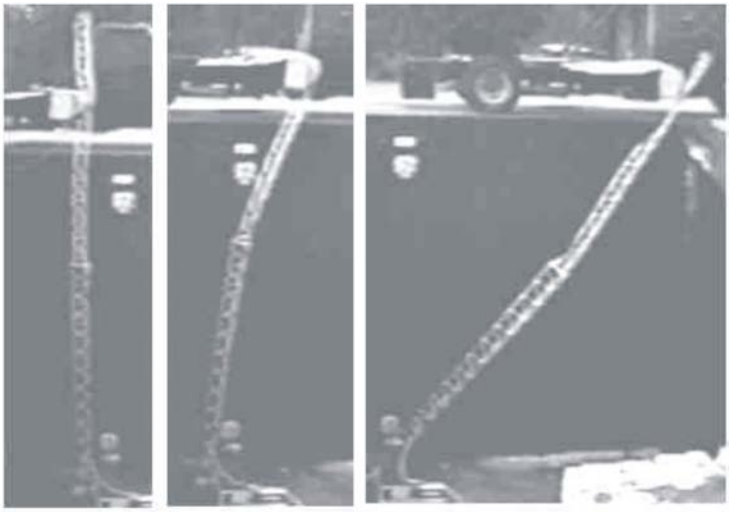


Full-scale test

Figure 6-2. Impact events from finite element analysis (FEA) simulation and full-scale test — impact speed 140 km/h; impact on side; rigid impactor

4 ms 38 ms 104 ms

FEA simulation



4 ms 38 ms 104 ms

Full-scale test

Figure 6-3. Impact events from finite element analysis (FEA) simulation and full-scale test — impact speed 140 km/h; impact on apex; top mass 5.44 kg; rigid impactor

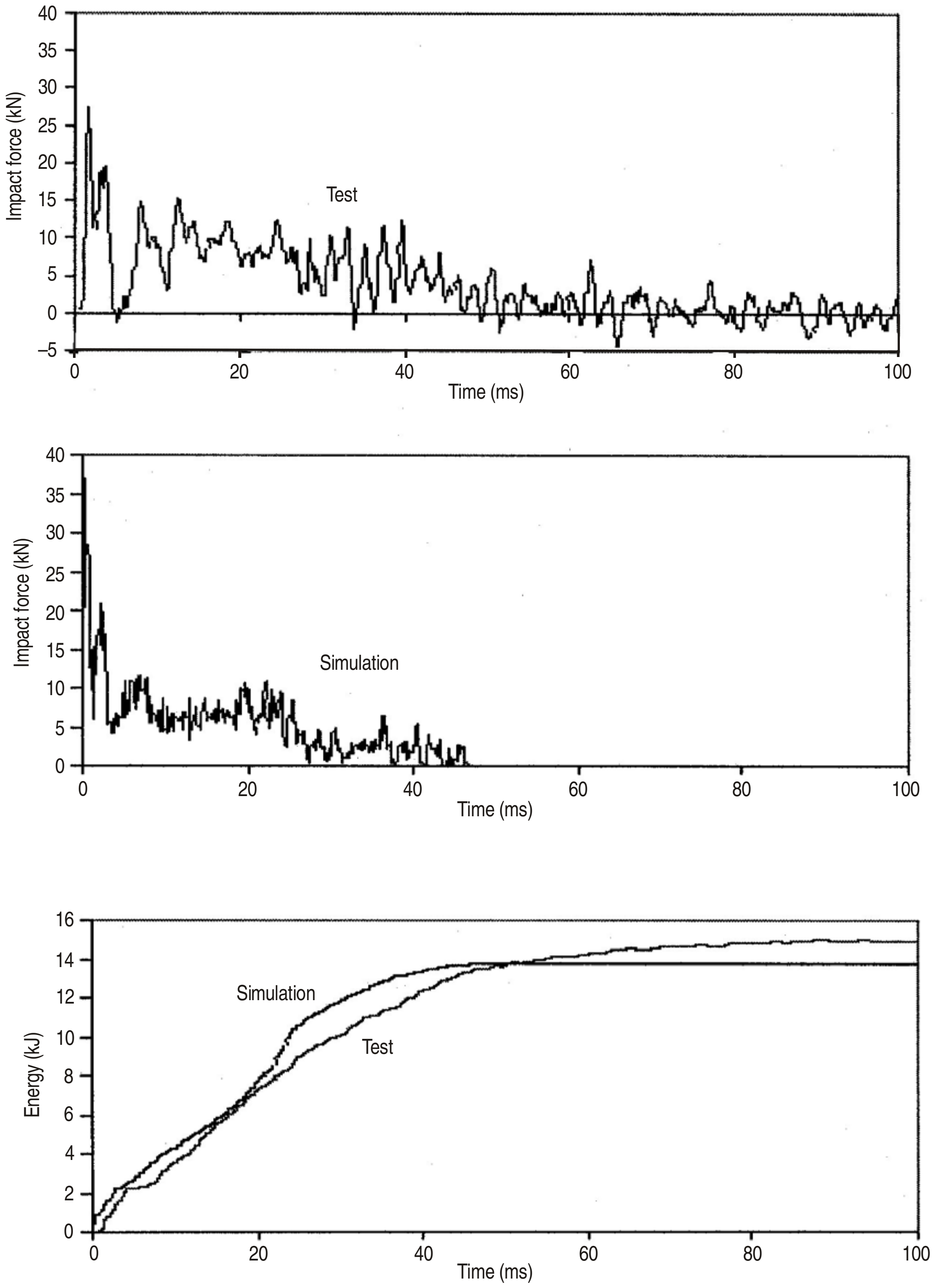


Figure 6-4. Impact force and energy — impact speed 140 km/h; impact on side; rigid impactor

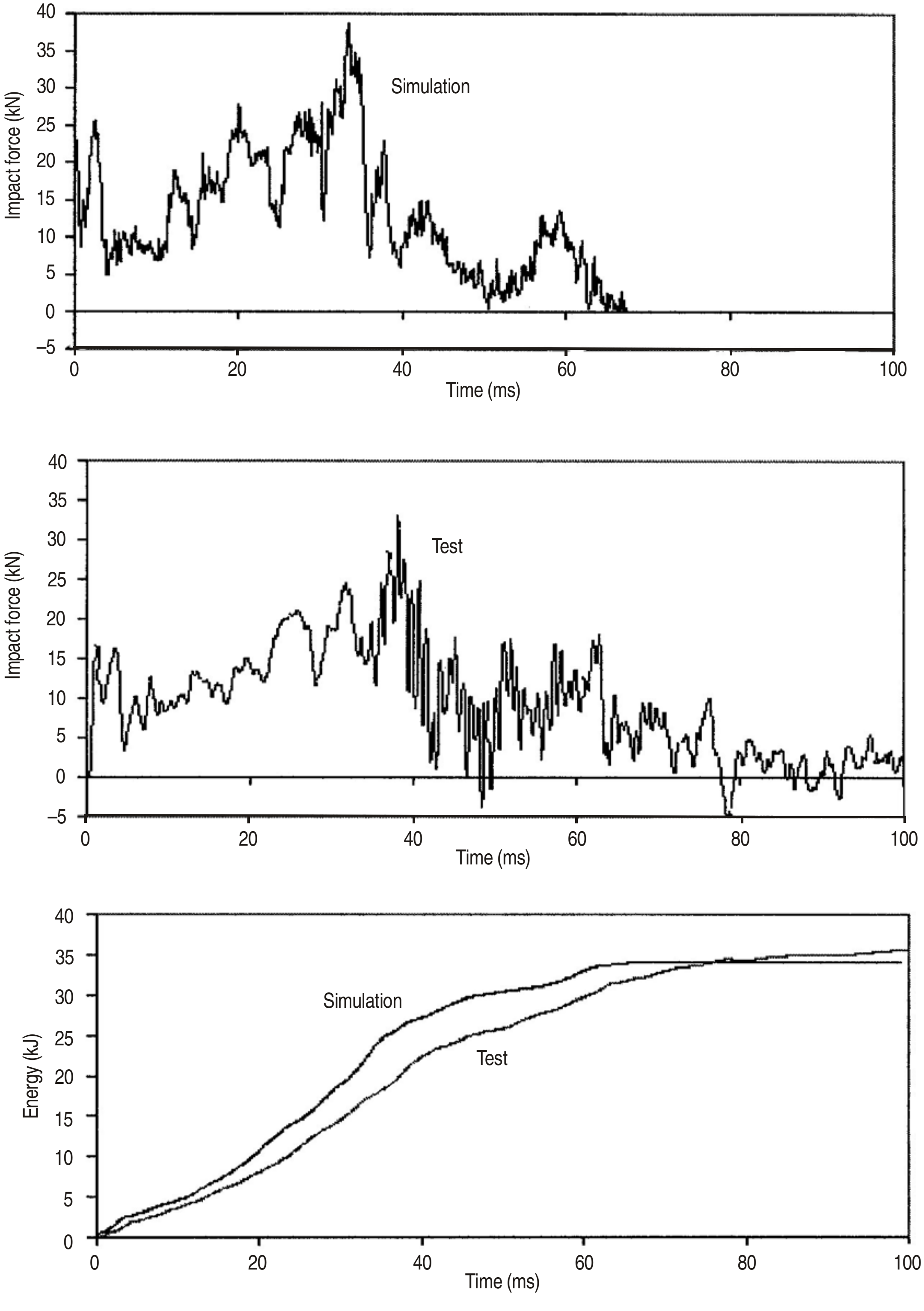


Figure 6-5. **Impact force and energy —impact speed 140 km/h; impact on apex; top mass 5.44 kg; rigid impactor**

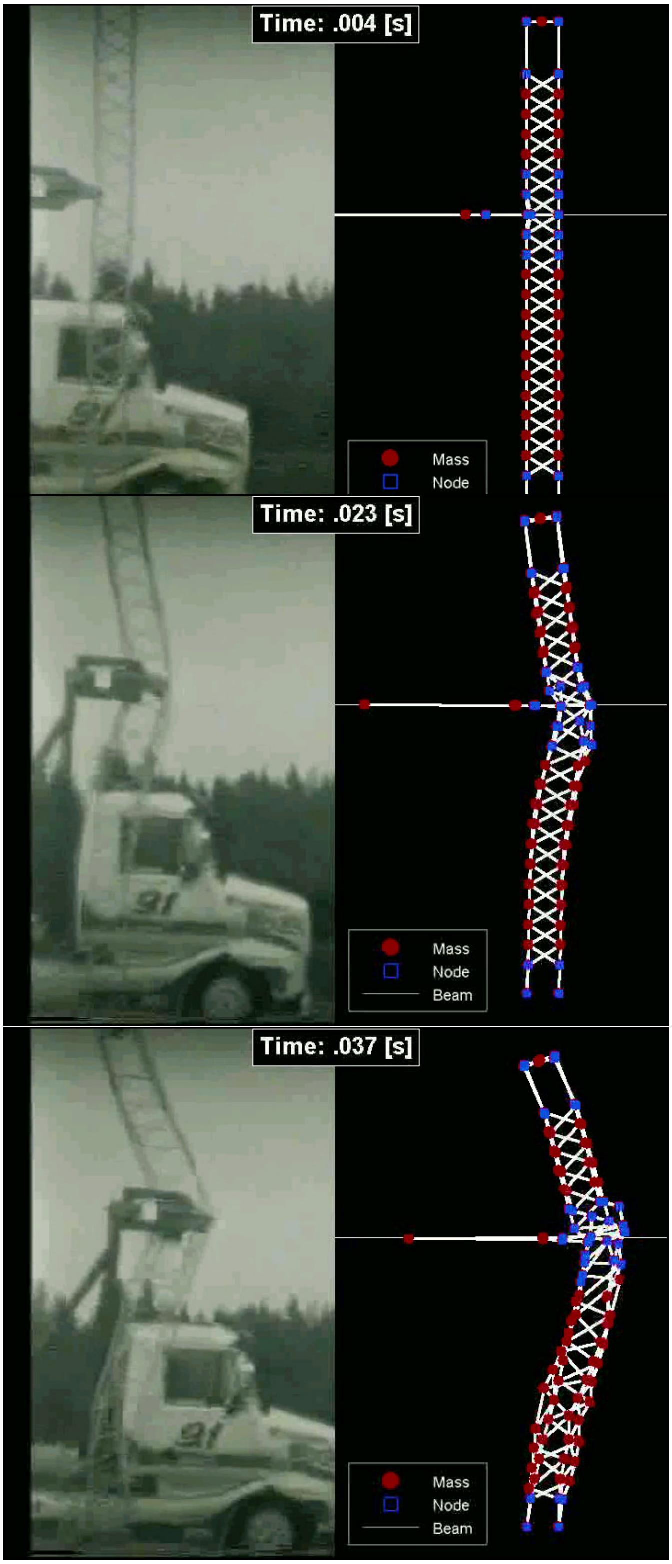


Figure 6-6. Comparison between actual deformation and that resulting from the hybrid analysis

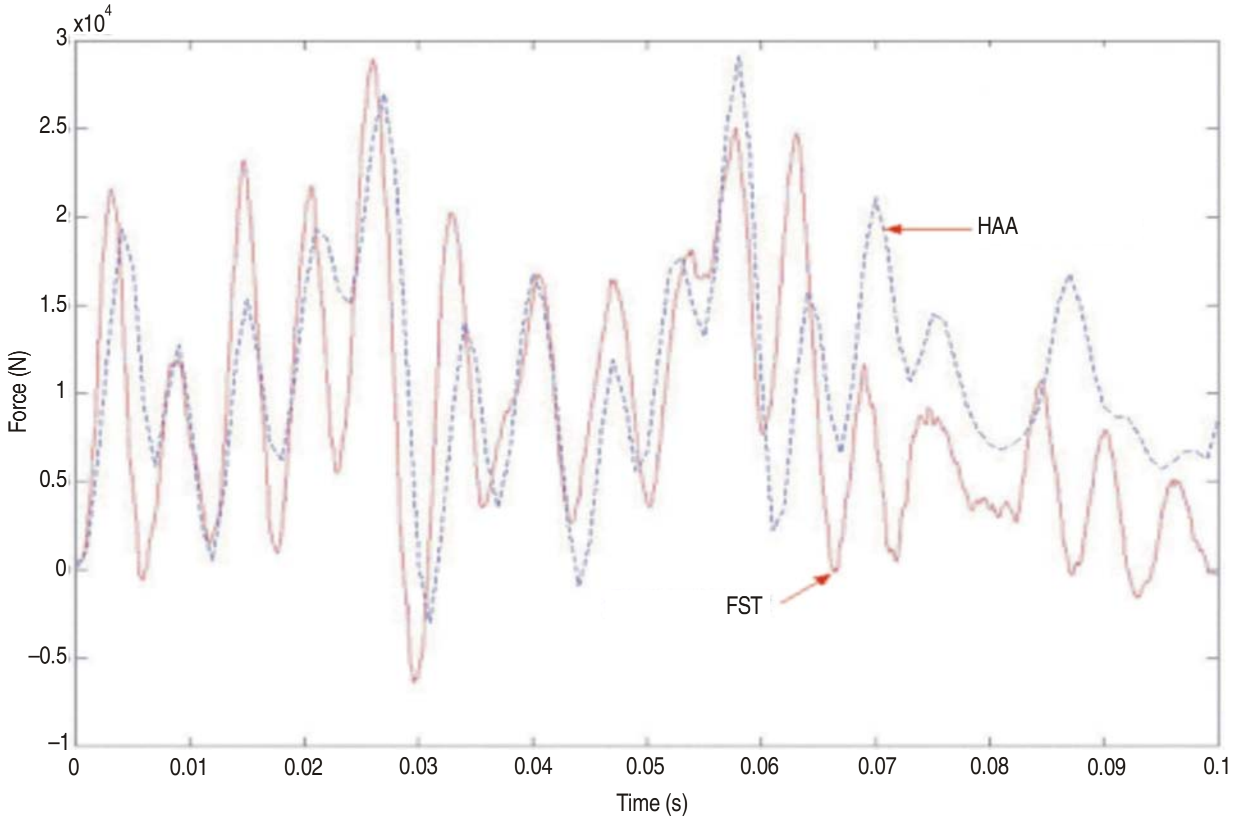


Figure 6-7. Impact forces calculated using the hybrid analysis approach (HAA) compared to results obtained from full-scale testing (FST)

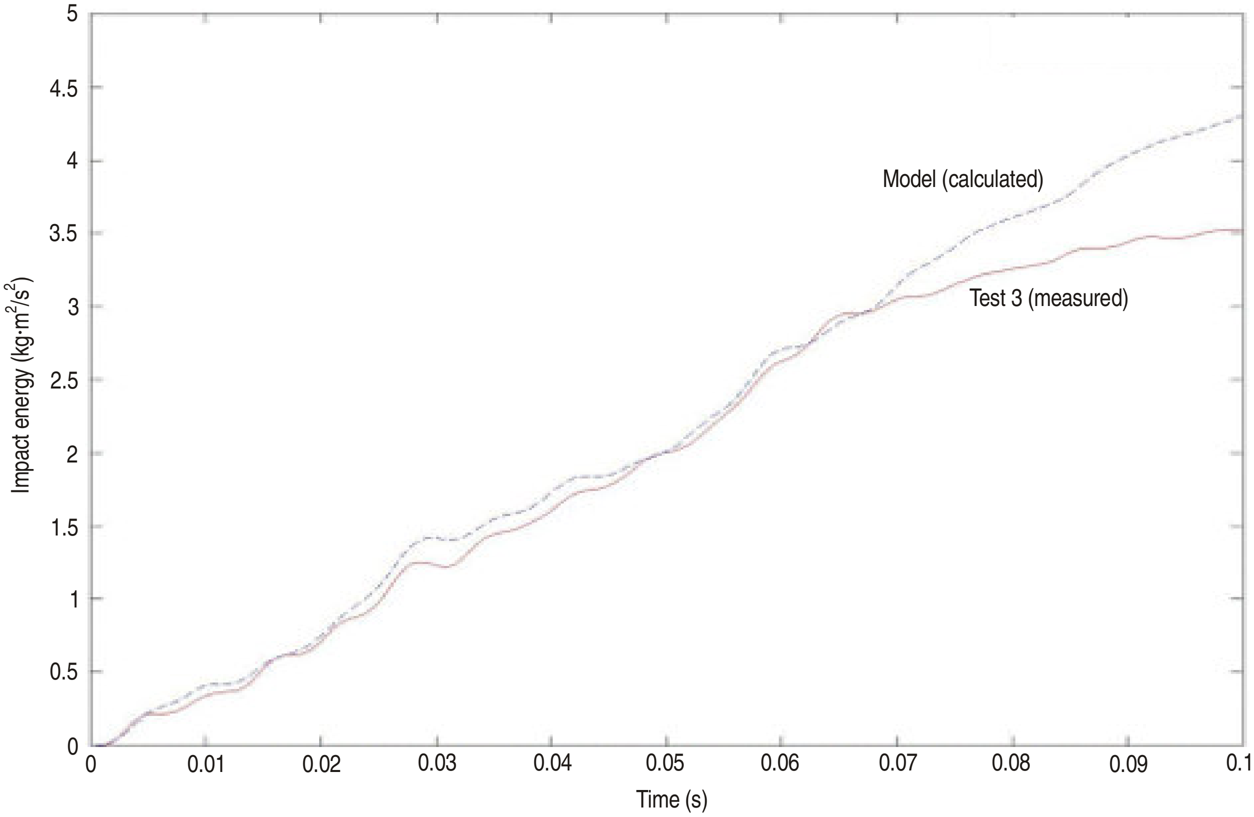


Figure 6-8. Impact energy calculated using the hybrid analysis approach compared to results obtained from full-scale testing

Chapter 7

INSTALLATION, INSPECTION AND MAINTENANCE

7.1 GENERAL

7.1.1 The basic purpose of visual and non-visual navigational aids systems is to aid in the safe operation of aircraft. Therefore, the highest standards of maintenance are required.

7.1.2 Once a navigational aids system is installed, its usefulness depends on its serviceability, which in turn depends on the effectiveness of the maintenance work carried out. It is essential to establish a comprehensive, routine maintenance system for servicing visual and non-visual aids and their supports so that the installations comply with the specified requirements, including those for frangibility.

7.2 INSTALLATION

7.2.1 Frangible structures should be installed in accordance with the recommendations of the hardware supplier. This refers to the structure, any cabling and connectors, and the base on which the structure is fitted.

7.2.2 A frangible structure no longer meets requirements if the structure itself is used as a climbing frame or is denigrated by the addition of a fixed ladder. The total structure should be maintained either by equipment that can easily be moved into position and then easily raised and lowered, or by lowering the structure to the ground.

7.2.3 Firm bases are essential for any precision visual or non-visual navigational aid. The design of the base should therefore provide maximum stability. Navigational aids are commonly supported on a concrete base, which should not be an obstacle to an aircraft overrunning an installation. This objective is achieved either by depressing the base below ground level or by sloping its sides so that the aircraft comfortably rides over the base. Where the base is depressed, the cavity above the base should be back-filled with appropriate material. This, together with the frangible construction of the navigational aid and its supports, ensures that no substantial damage is sustained by an aeroplane should it run over the aid.

7.3 INSPECTION AND MAINTENANCE

7.3.1 An inspection programme should be implemented in accordance with the recommendations and/or requirements of the hardware supplier to ensure its continued operation as a frangible device. The inspection process should form part of the aerodrome safety management system and should ensure that all hardware and associated structures are inspected and maintained to the highest standards of safety. It should also allow both the aerodrome operator and the ATS provider to be fully aware of the current condition of all its facilities. Additionally, by using a formal inspection process, the following objectives are fulfilled:

a) ensuring compliance with the Standards and Recommended Practices of Annex 14 and the certification requirements of the National Civil Aviation Authority;

b) ensuring that any failures, unserviceabilities or obstructions that may affect the safety of aircraft and personnel on the aerodrome are promulgated appropriately and planned rectification initiated;

c) ensuring compliance with the aerodrome's safety management system; and

d) providing a recorded audit trail in the event of an accident or incident.

7.3.2 All aerodrome structures and facilities that are required to be frangible should be inspected within the overall aerodrome inspection process, which may take the form of a three-level process as follows:

a) *Level 1.* Routine daily inspections covering the entire aerodrome. This level is designed specifically to provide an overview of the general condition of all manoeuvring area facilities. These inspections, carried out a minimum of four times per day or four times during the operating hours of the aerodrome, should check for major failures, gross misalignments or unserviceabilities of all facilities, including those which are made frangible. This includes the general physical condition of all frangible aerodrome ground lighting on and adjacent to the runway and taxiways. Additional checks should be made at dusk to check for light outages and misalignments.

b) *Level 2.* More detailed daily inspections whereby the aerodrome is divided into a number of small areas and, where possible, inspected on foot, allowing for a more comprehensive assessment to be made. During this level of inspection all frangible visual and non-visual aids should be checked for damage, including their foundations and anchorage points. Particular attention should be paid to the facilities within the runway strip and the runway end safety area. In addition, each full approach lighting system, its cables, light fittings, masts and other support structures should be checked twice a year.

c) *Level 3.* Management inspection/audit carried out by senior operations and engineering staff. This level is essentially an audit of the level 2 inspection and it ensures that operations and engineering managers are fully involved in the overall airside inspection process within the safety management system. Within this level staff should physically check all facilities that are required to be frangible.

7.3.3 Inspections and audits at all three levels together with the identities of the personnel that have carried them out should be recorded in detail. Additionally, at all three levels there should be a formal process of fault-reporting and confirming rectification to the appropriate department. The three-level inspection process should be the subject of regular review to ensure the system benefits from process improvements, technological and other changes. The inspection process described in 7.3.2 should enable the highest degree of safety to be maintained for aircraft operations and should ensure that best-practice safety management principles are applied to all airside areas.

7.3.4 Furthermore, a programme of maintenance should be developed, implemented and carried out in accordance with the recommendations and/or requirements of the hardware supplier. All maintenance should be carried out by trained and competent staff and all procedures should ensure that facilities are safe and remain functional and provide aircrew with the correct information, lighting pattern and guidance.

7.3.5 Additional procedures should also be set up to inspect frangible facilities that may be subject to high winds or other adverse weather or loading such as jet blast.

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