FINAL INVESTIGATION REPORT

ON

THE COLLAPSE OF ROOF STRUCTURE OF

CHAN TAI HO MULTI-PURPOSE HALL OF

HU FA KUANG SPORTS CENTRE OF

CITY UNIVERSITY OF HONG KONG

TAT CHEE AVENUE, KOWLOON

ON 20 MAY 2016

(The Redacted Version)

For information provided to the Buildings Department
on confidential or without prejudice basis, and
in order not to affect any legal actions that may be taken,
certain parts of paragraphs 10.3 and 10.4
of this Report have been redacted.

屋宇署
BUILDINGS DEPARTMENT

Buildings Department

May 2017

Introduction

1. On 20 May 2016 at about 2:30 pm, the roof structure of a multi-purpose sports hall, named Chan Tai Ho Multi-purpose Hall (the Sports Hall), in Hu Fa Kuang Sports Centre (the Sports Centre) of the City University of Hong Kong (the CityU) collapsed. There was a greenery cover (the GC) of shallow soil depth on the top of the roof structure (the roof structure). Two staff members of CityU sustained minor injuries and a third individual was in shock in the incident. They were hospitalised for treatment, and discharged later on the same day.

2. The Buildings Department (the BD) carried out inspection immediately and did not identify any obvious structural danger in other parts of the Sports Centre. The BD also carried out urgent stabilisation and site clearance works in parallel with an investigation into the collapse incident (the incident). The purposes of BD's investigation are to assess the structural safety of the roof structure with respect to its design and construction as well as its conditions before the incident, with a view to determining the cause(s) of the collapse.

3. On 17 June 2016, the BD released a preliminary report (the Preliminary Report) covering its initial findings on the surrounding circumstances and identification of factors that might possibly contribute to the collapse of the roof structure. In early September 2016, the stabilisation and clearance works were completed, and the site was handed over to CityU.

4. This is the Final Report, which includes all the issues covered in the Preliminary Report, on the incident and it presents:

(a) BD's findings from its investigation; and

(b) BD's conclusions of these findings.

Methodology

5. The information stated in this Final Report has been based on the following :

(a) Site inspections and investigation by the BD conducted after the incident;

(b) Records kept by the BD including approved building plans, drainage plans and structural plans and the associated documents of the Sports Centre (the Approved Plans);

(c) Information, documents and materials obtained from CityU including but not limited to the Report of the Investigation Committee for the CityU Sports Hall Incident (The Redacted Version) released on 10 June 2016 (the IC Report[1]), the web site of the Investigation Committee for the CityU Sports Hall Incident, incident reports[2], CCTV footage, and contract documents[3] for the roof greening on campus buildings (the Roof Greening Project[4]), etc.;

(d) Records of interviews after the incident conducted by the BD with relevant personnel involved;

(e) Information obtained from other Government departments including aerial photos and rainfall records;

(f) Laboratory test results of samples taken at the scene after the incident; and

(g) Desktop study, analyses, computer modelling and simulation including the findings of an external expert commissioned by the BD.

The Subject Building and Observations

6. *The Sports Centre and the Sports Hall*

6.1 The Sports Centre is situated in the Amenities and Sports Block, a 6-storey reinforced concrete (R.C.) construction completed in January 1990[5]. Located at Floor 05 of the Sports Centre, the Sport Hall is a multi-purpose hall with clear headroom of about 10m and a gallery sitting area at Floor 06.

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1 http://www.cityu.edu.hk/ic/report/CityU_IC_Report.pdf.

2 These are incident reports (事件報告書) prepared by the Campus Development and Facilities Office of CityU in response to complaints and reports in relation to the Sports Hall prior to the collapse incident on 20 May 2016.

3 According to page 8 of the IC Report, the contract was signed by CityU with a contractor for the "Design and Build: Roof Greening on Campus Buildings" project.

4 Paragraph 13 of BD's Preliminary Report.

5 As specified in the Occupation Permit (the OP), the Amenities and Sports Block was permitted for amenities and sports complex, carparking spaces and a swimming pool for non-domestic use.

7. *The Roof*

7.1 The main structural element of the roof structure of the Sports Hall was a space truss system (the STS) supported by R.C. beams at the main roof of the Sports Centre named Floor 07 (the Main Roof), and its rooftop was called Floor 08 (the Roof). According to the Approved Plans, the Roof was a flat roof without the provision of the GC. The records of the BD did not indicate any submissions of alterations and additions (A&A) works for the Roof under the Buildings Ordinance (the BO).

7.2 The Roof measured 39m long and 33m wide having an area of 1,287 m^2, was accessible via a cat ladder from the Main Roof only. Neither protective barriers at its periphery nor surface channels or gutters was provided. According to the Approved Plans, the Roof was designed to have a fall in a gradient of 1 in 80 towards two opposite sides for discharge of rainwater onto the Main Roof where drainage outlets and surface channels were provided. *(**Annex 1** – Roof Plan, **Annex 2** – Section A-A)*

7.3 According to the Approved Plans, the STS was 42m long, 36m wide and 2.25m high. It was composed of hot rolled rectangular hollow steel sections as the chords and cold formed circular hollow steel sections as the webs, and supported on 4 sides by a series of bearings at about 3m intervals along the peripheral beams on the Main Roof. Based on the Approved Plans, the STS provided support for a 125mm thick R.C. slab (the Roof Slab) served as the decking of the Roof, 20mm thick screeding, two woodwool layers, building services and fittings. *(**Annex 3** – General Structural Layout of the STS)*

8. *The GC on the Roof*

8.1 According to the BD's investigation, the GC was about 35m long, 29m wide and 100mm thick and had an area of 1,015 m^2. It was a modular green roof assemblage laid on the Roof, layer by layer, with substrate materials, soil and pre-planted modular trays. It rested on top of the Roof by its own weight without any fixings and was restrained at its four edges by freestanding perforated L-shaped, bookend like, metal edge plates of 120mm high.

8.2 The GC was irrigated daily under the control of an automatic

irrigation system. All the piping was laid in the GC without any fixings. It was noted in the course of investigation that a newly completed water tank[6] served to supply water for irrigation for various new green roofs at different locations of the campus under the Roof Greening Project as mentioned in paragraph 5(c) above.

8.3 No new or additional drainage works on the Roof were identified. According to the design of the GC, excessive water was discharged away from the GC by either surface run off (i.e. on the surface of soil and vegetation) or seepage through the GC down to its substrate materials, flowing along the sloping surface of the Roof by gravity and passing through the side openings of metal edge plates. Water discharged away from the GC (Floor 08) continued to fall onto the Main Roof (Floor 07).

8.4 According to page 14 of the IC Report, Campus Development Facilities Office (CDFO) staff involved in landscaping work advised that the soil samples of the same type of greenery cover taken from the adjoining Wei Hing Theatre (WHT) when the greenery cover was removed from WHT almost immediately after the incident appeared, based on visual inspection, to be very different from the materials used for weight measurement demonstration in the presence of the CDFO staff. In addition, according to page 16 of the IC Report, the set of data used by an Authorized Person involved in the Roof Greening Project could have been based on design calculations superseded in 1989.

BD's Findings

9. As revealed from the surrounding circumstances and laboratory test results, the STS and the Roof Slab were generally in line with the Approved Design[7] but the following discrepancies were identified and the loading imposed on the STS was beyond the extent anticipated or considered in the Approved Design *(**Annex 4** – Indicative Section of the Roof (Before Collapse))*:

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[6] A&A plans for the construction of a glass reinforced fibre water tank and associated supporting plinths at the roof of Academic 1 were submitted to the BD in July 2015 by an Authorized Person and a Registered Structural Engineer under the BO. The Registered General Building Contractor of the works certified in a specified form (Form BA 14) that the works were completed in December 2015.

[7] Refers to the design shown in the Approved Plans.

(a) a layer of screeding (the Bottom Screed) thicker than the original design on the top of the Roof Slab, and an additional layer of screeding underneath the waterproofing membrane of the Roof (the Top Screed); and

(b) the GC.

10. *Bottom Screed and Top Screed*

10.1 According to the Approved Plans[8], the approved imposed load (i.e. live load) of the STS was 0.75 kPa and the approved dead load was 4.25 kPa, which had taken into account of the loading of different layers of materials[9] imposed thereon and mounted underneath.

10.2 As revealed from the concrete core samples collected on site after the incident, there were two layers of screeding and one layer of foam-type insulation on top of the Roof Slab, which were different from the Approved Design. While the loading of this insulation layer (0.13 kPa) identified has no significant impact, the overall dead load imposed on the STS including the weight[10] of the Roof Slab, Top Screed (0.88 kPa), and the Bottom Screed (1.45 kPa) on the STS increased to 5.75 kPa, which is about 35% more than the approved dead load of 4.25 kPa. The thickness of the Top Screed and the Bottom Screed measured up to about 64mm and 93mm respectively in contrast to the screeding of 20mm thick in the Approved Design.

10.3 In response to BD's enquiry, [redacted] Having considered the aerial photos from 1988 to 2016, witness statements of the relevant personnel[11] involved in the construction of Amenities and Sports Block and the concrete core samples, [redacted]

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8 The design imposed load and dead load were specified in Drawing No. HKCP/101 approved by the Building Authority (the BA) on 3 February 1989. The self-weight of the STS of 0.5 kPa was accounted separately in the approved structural plans.

9 These include Roof Slab, 20mm thick screeding, two layers of woodwool boards, building services, fittings, etc.

10 Based on average values of laboratory test results of the samples collected on site.

11 Authorized person, architectural designer and project structural engineer of the construction project and staff of the then Buildings Ordinance Office which is the former name of BD.

[redacted]

10.4 [redacted] BD has no records of approval of plans in respect of the Top Screed.

10.5 The increase of loading exceeding the approved dead load of the STS as stated in the Approved Plans was pertaining to the factor of *overloading due to the Roof Slab underneath the GC* identified in paragraph 18(h) of the Preliminary Report.

10.6 Both the Bottom Screed and the Top Screed on the Roof were building works under the BO which required the BA's prior approval of plans and consent for commencement for works before such works should be executed on the Roof.

11. *The GC*

11.1 According to the laboratory measurements on the samples of the GC collected on site after the incident, the loading from the GC is about 1.32 kPa under fully saturated condition which is about 100% more than the result in the Measurement Report for the GC (0.656 kPa)[12] as obtained from CityU. Based on the same laboratory measurements, the net weight of the substrate materials was about 4% of the weight of the fully saturated GC.

11.2 The increase of loading exceeding the approved dead load of the STS was pertaining to the factor of *overloading due to the laying of the GC on the Roof* identified in paragraph 18(i) of the Preliminary Report.

11.3 As to whether the laying of the GC on the Roof constituted building works requiring the BA's prior approval of plans and consent for commencement of works, it would depend on the degree of fixation, permanence, intended use and extent of the GC, associated building works and provision of other facilities in and around the GC, and ease of assembling and ease of removal of the GC. After taking into account all relevant

[12] Page 9 of IC Report refers.

considerations, including but not limited to the nature and design of the GC as mentioned in paragraph 8 above, the BA is of the view that the laying of the GC[13] did not constitute building works under the BO. As the GC did not involve building works under the BO, the BA's prior approval of plans and consent for commencement of works was not required.

11.4 The OP issued by the BA under the BO had not specified the use of the Roof. According to the Approved Plans, the Roof was designated as a flat roof under the BO and it was of inaccessible roof design with no protective barrier provided at the periphery. The Roof was a restricted area for maintenance personnel only and access to the Roof required a security procedure. In any event, the GC is a facility at the Roof. The Roof remained a flat roof with restrictive access for carrying out maintenance work for the GC. In view of the above, the BA is of the view that the laying of the GCdid not constitute a change in use under the BO.

12. *Combined adverse effect on the discharge of water on the Roof*

12.1 The loading imposed on the STS including the weight of the Roof Slab, the Bottom Screed, the Top Screed and the GC was about 7 kPa when the GC was fully saturated, which is about 65% more than the approved dead load on the STS (i.e. 4.25 kPa) or over 40% more than the total designed dead load and live load on the STS (i.e. 5.0 kPa).

12.2 The loading imposed on the STS increased due to the laying of the GC and the two layers of screeding together with the water so absorbed by the GC and retained on the Roof. Owing to the incremental increase of loading, the overall deflection of STS gradually increased and the gradient of the Roof flattened. The rate of discharge as well as the flow of water was affected, which would have been further aggravated by the rough and uneven surface of soil and vegetation of the GC. Water ponding at these discrete locations was resulted when more water was added on the GC.

12.3 The reduced gradient of the Roof had impeded the smooth discharge of water causing puddles of water in the GC before the incident. The water ponding so induced further increased the loading on the Roof.

[13] As mentioned in paragraph 1 of this Report, the GC refers to the greenery cover of shallow soil depth on top of the roof structure of the Sports Hall. The BA's view that the laying of the GC did not constitute building works under the BO is based on the facts of this case and this is not to be taken that all greenery covers are not building works under the BO.

12.4 The combined effect due to the above two factors pertaining to overloading as mentioned in paragraphs 10.5 and 11.2 above gave rise to the relevancy of *water ponding on the Roof* as identified in paragraph 18(j) of the Preliminary Report.

13. *Other findings not contributory to the collapse*

13.1 In the course of the BD's investigation, two other discrepancies between the Approved Design and the samples collected on site after the incident were identified. However, it was revealed after structural analyses that they were not contributory to the collapse as set out below.

13.2 *Metal studs for the control of gradient of the Roof*

13.2.1 According to the Approved Design, the gradient of the Roof towards two opposite sides for discharge of rainwater was effected by means of metal studs of varying heights fixed above different locations of the STS. Samples collected on site after the incident revealed that all the metal studs were shortened and the roof surfaces fell towards all four sides. That being the case, adequate gradient was generally maintained and no structural concern was identified.

13.3 *Guided bearing supports*

13.3.1 According to the Approved Design, guided bearing supports were the supporting points where the STS were seated on the R.C. beams at the Main Roof. On-site inspection and samples collection after the incident revealed that for some guided bearing supports, dowel bars of larger diameter were used and their position was shifted, which led to the edge distance between the beam surface and dowel bars (commonly referred as *concrete cover*) less than the Approved Design. Nevertheless, according to the laboratory test results of the concrete samples collected on site after the incident, the ultimate shear resistance and allowable capacity were considered capable in resisting the required shear force acting upon the guided bearing supports under the original design loads. As a result, the discrepancies are not related to the structural performance of the STS.

The Incident

14. Based on the information available, BD's findings in its

investigation as well as the structural analysis, the incident is depicted in paragraphs 15 and 16 below.

15. *Loading condition before the collapse of the roof structure*

15.1 The approved imposed load was 0.75 kPa and the approved dead load was 4.25 kPa. It was revealed in the BD's investigation that the dead load imposed on the STS before laying the GC was already increased to about 5.75 kPa. The GC further increased the loading imposed on the STS. Such increased loading varied as the weight of the GC varied with different water contents.

15.2 While the Roof was designed to have a fall in a gradient of 1 in 80, the actual gradient was reduced by the loading imposed on the Roof. With the addition of loading, the overall deflection of the STS increased and the gradient of the Roof flattened.

15.3 On 10 May 2016, three Amber and two Red rainstorm signals were issued, and over 90mm of rainfall was recorded at a weather station in the district of Kowloon Tong. The downpour and irrigation water were absorbed by the GC and its weight increased when excessive water could not be discharged effectively. There was a report that some small cement chips had fallen from the roof of the Sports Hall during the examination period.

15.4 The irrigation system for the GC continued to operate on a daily basis after 10 May 2016. From the information available, puddles of water on the GC were observed on 13 and 17 May 2016.

15.5 From the samples collected on site after the incident, computation with three-dimensional contouring method was employed for the projection of gradient profile of the Roof. It was revealed that coupling with the effects of different layers of materials with varying thickness and the resultant deflection due to the loading imposed on the Roof according to the results of structural analyses, the gradient of considerable areas was reduced and the flow of water impeded. As a result, water puddles at these areas were observed. Water ponding occurred at these areas when more water was added on the GC.

15.6 Structural analyses revealed that a web member of the STS was approaching its ultimate capacity and became critical when the GC was fully

saturated and ponding occurred at localised areas. Additional weight of water due to localised ponding on some parts of the GC which were already under a fully saturated condition would be sufficient to trigger the collapse of the roof structure.

16. *Collapse of the roof structure on 20 May 2016*

16.1 In the morning of 20 May 2016, there was slight rainfall and the GC was irrigated as usual. With the additional weight of water, the critical web member reached closer to its ultimate capacity. Due to the burst of water pipes[14] mounted underneath the STS at about 2:15 pm, i.e. 15 minutes before the collapse, people working in the Sports Hall evacuated. Water continued to pour down and covered most of the floor area of the Sports Hall. The water from the burst pipes had also resulted in likely wetting of the woodwool boards underneath the Roof Slab, thus inducing incremental load on the STS.

16.2 At the time of reaching the ultimate capacity, the critical web member buckled [15] and the loading carried by the failed member was instantaneously redistributed to other members. Subsequently, coupled with continual wetting of the woodwool boards, those affected members eventually reached their ultimate capacities and failed. The structural integrity of the entire STS failed as a result of failure of more and more members. With the loss of structural integrity, the STS was unable to uphold its position and started to distort, which induced tremendous horizontal force at its supports. The dowel bars at its supports were pulled out, and the roof structure collapsed to the floor of the Sports Hall.

Conclusion

17. In the Preliminary Report, based on the information available at that time, the BD identified eleven factors[16] that might possibly contribute to

[14] Based on the available information, the only water-carrying pipes mounted underneath the STS were fire services sprinkler pipes.

[15] Buckling is a mode of failure under compression of a structural component. It is characterised by a sudden sideway failure of a structural member subjected to high compressive stress, when the compressive stress at the point of failure exceeds the ultimate capacity of the member.

[16] The eleven factors were (a) design fault of the STS; (b) use of substandard materials for the STS; (c) discrepancies in the construction of the STS and non-conformance to the original design; (d) poor workmanship of the STS; (e) overloading due to excessive building services mounted underneath the STS; (f) lack of maintenance of the STS; (g) unauthorised alteration of

the collapse of the roof structure. After the examination of surrounding circumstances, the relevant information, documents and materials available, and structural analyses and computer modelling, the BD identified no new factors contributing to the collapse. Based upon the findings and all relevant considerations, the BA is of the view that the collapse was caused by overloading and was triggered by the additional weight of water due to localised ponding on the GC, and that all the other factors identified in the Preliminary Report are considered not the direct causes of the collapse but the following three factors are contributing to the incident:

(a) *overloading of the Roof due to thickening of the screeding of the roof structure*;

(b) *overloading of the Roof due to laying of the GC*; *and*

(c) *overloading of the Roof due to localised water ponding on the GC.*

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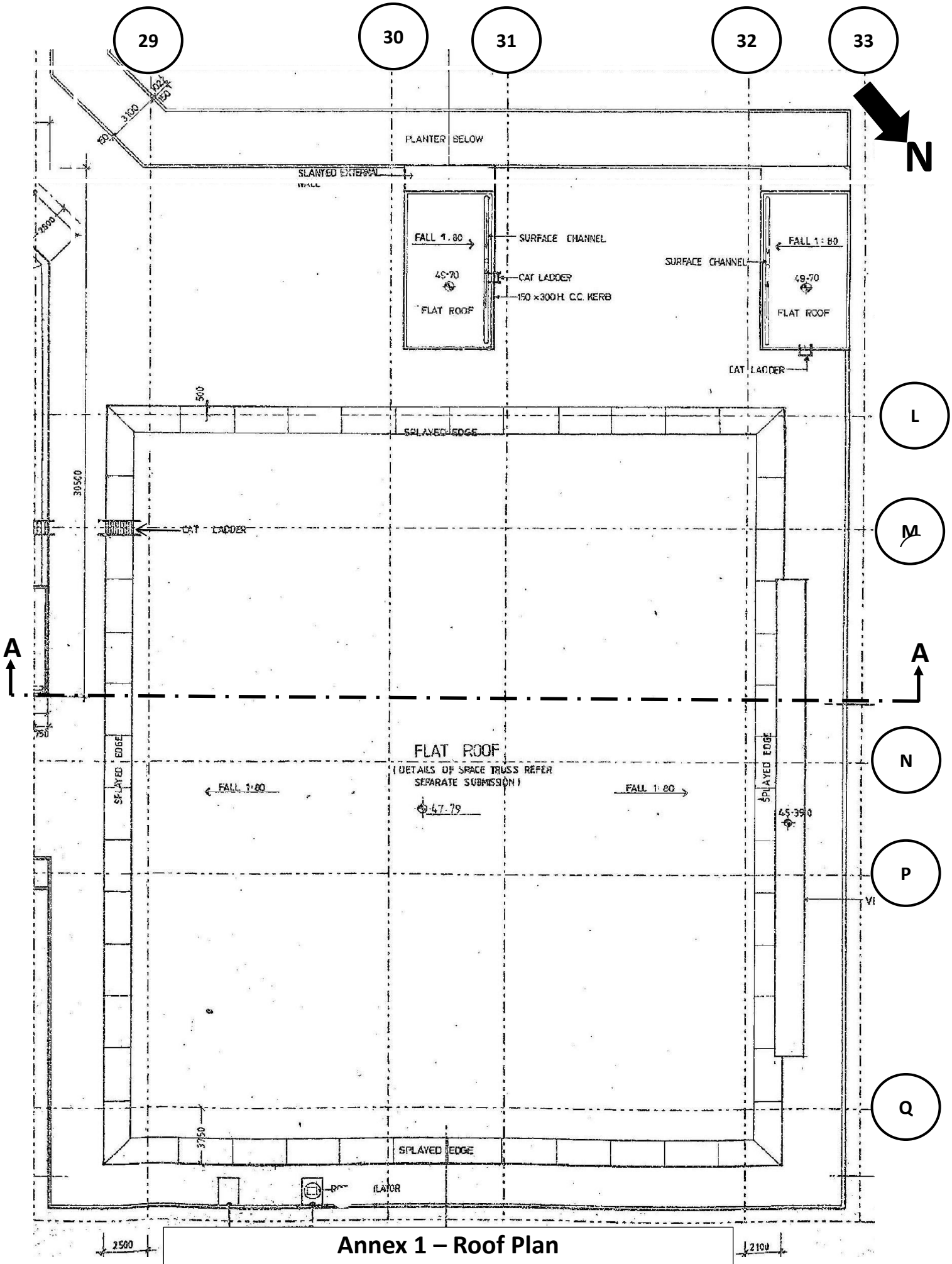
the STS; (h) overloading due to the roof slab underneath the greenery cover; (i) overloading due to the installation of greenery cover on the Roof; (j) deficient drainage system and water ponding on the Roof; and (k) misuse of the Roof.

Abbreviations and Glossary of Terms

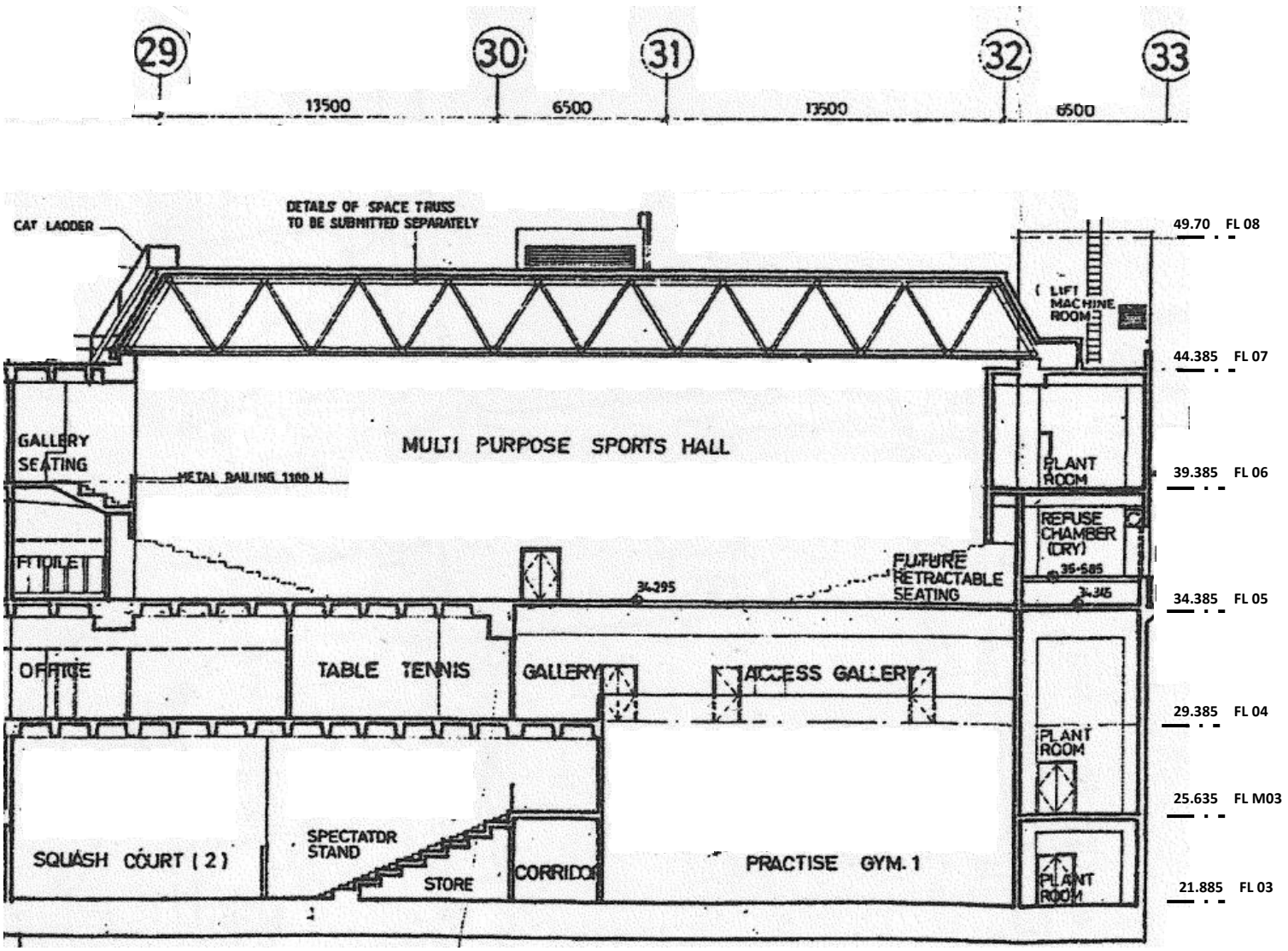
A&A	Alterations and additions
Approved Design	Design shown in the Approved Plans
Approved Plans	Records kept by the BD including approved building plans, drainage plans and structural plans and the associated documents of the Sports Centre
BA	Building Authority
BD	Buildings Department
BO	Buildings Ordinance (Cap. 123)
Bottom Screed	A layer of screeding built over the Roof Slab as revealed from the investigation
CityU	City University of Hong Kong
GC	Greenery cover
IC Report	Report of the Investigation Committee for the CityU Sports Hall Incident (The Redacted Version) released on 10 June 2016 by CityU
Main Roof	Refers to Floor 07 of the Sports Centre as shown in the Approved Plans
Preliminary Report	Preliminary Report on the Collapse of Roof Structure of Chan Tai Ho Multi-purpose Hall of Hu Fa Kuang Sports Centre of City University of Hong Kong Tat Chee Avenue, Kowloon on 20 May 2016 issued by the BD on 17 June 2016
R.C.	Reinforced concrete
Roof	Refers to Floor 08 of Chan Tai Ho Multi-purpose Hall as shown in the Approved Plans
Roof Greening Project	The "Design and Build: Roof Greening on Campus Buildings" project implemented by the Campus Development and Facilities Office of CityU in late 2015 as referred in the IC Report
Roof Slab	125mm thick R.C. slab served as the decking of the Roof as shown in the Approved Plans
Sports Hall	Chan Tai Ho Multi-purpose Hall
Sports Centre	Hu Fa Kuang Sports Centre
STS	The space frame as shown in the Approved Plans to support the Roof Slab, screeding, woodwool layers, building services and fittings, etc.
Top Screed	A layer of screeding underneath the waterproofing membrane of the Roof



Annex 1 – Roof Plan

附件 1 – 屋頂圖則

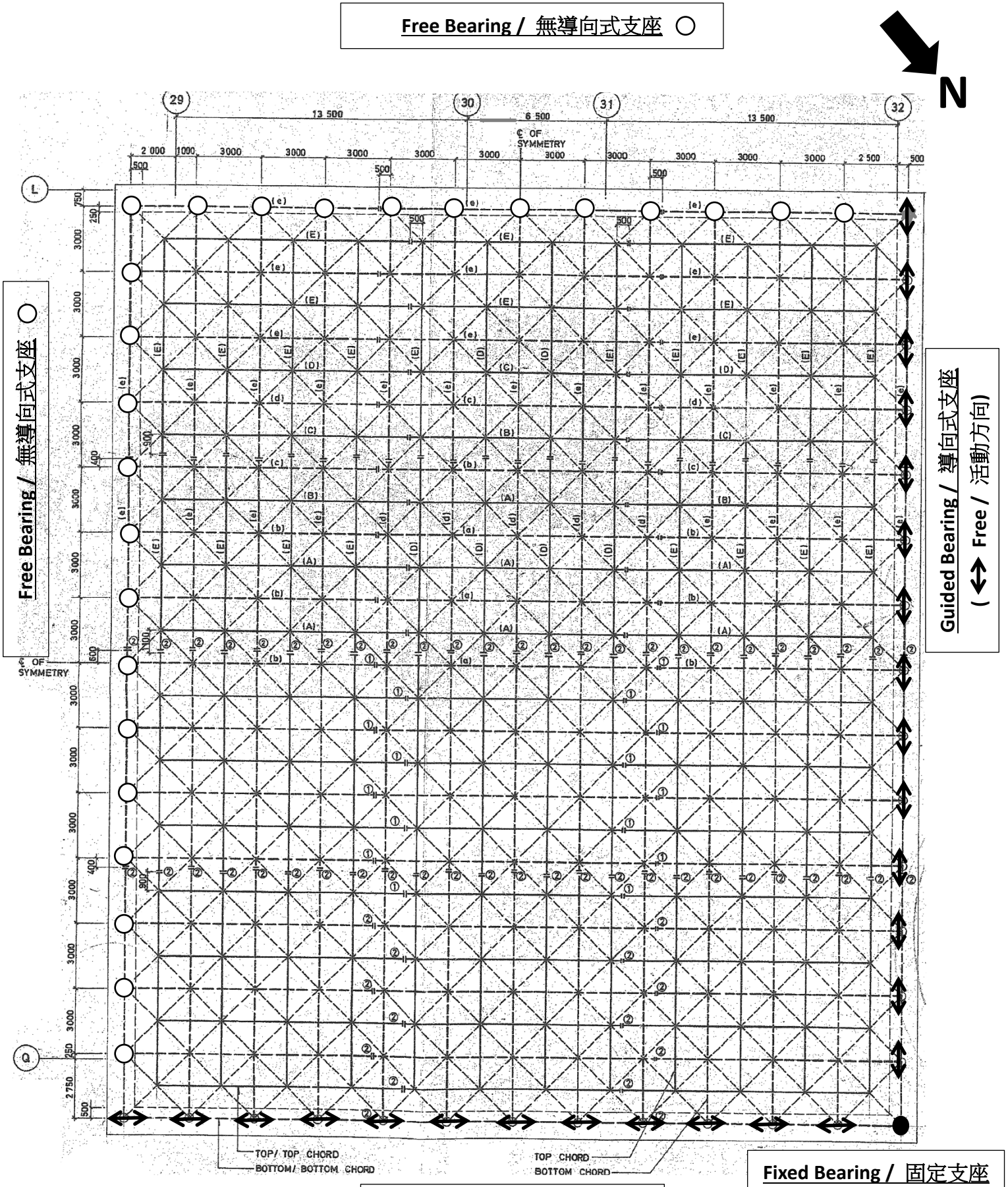
(Floor 08 / 08 樓)



Annex 2 – Section A - A

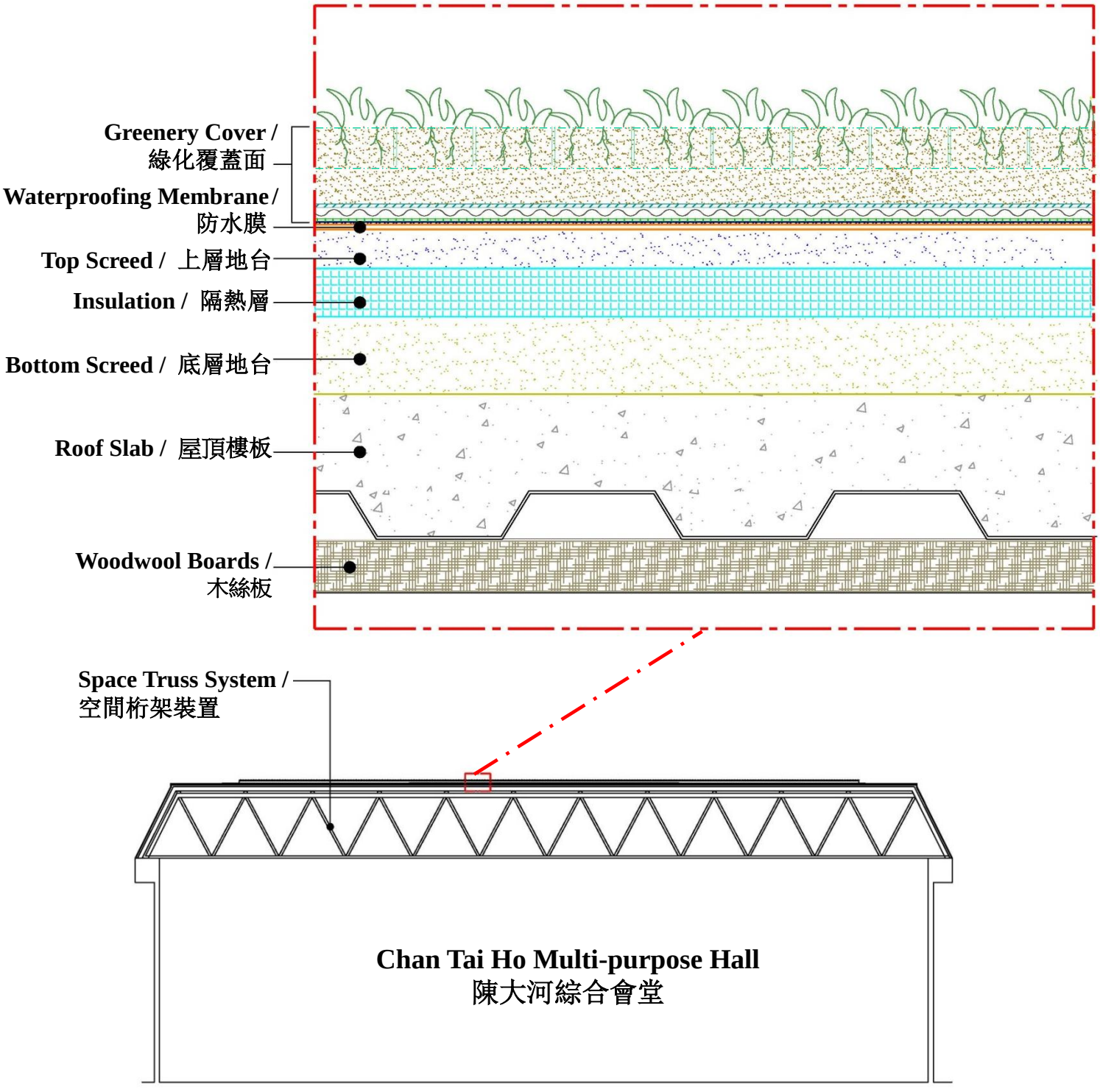
附件 2 – A - A 截面圖

(Hu Fa Kuang Sports Centre / 胡法光運動中心 **)**



Annex 3 – General Structural Layout of the STS

附件 3 – 空間桁架裝置的總體結構布置圖



Not to Scale / 不按比例

Note: **The diagram is indicative and for reference only.**

備註： 圖表僅作參考示意用途。

Annex 4 – Indicative Section of the Roof (Before Collapse)

附件 4 – 屋頂截面示意圖（倒塌事件發生前）