ACKNOWLEDGMENT

The authors of HKIE Transactions, vol. 25:1, pg. 29-43, “Design and construction of long-span single-layer dome structures by direct analysis”, would like to acknowledge the engineering design of “The Spectacle Roof” at MGM Cotai Macau is by Siu Yin Wai & Associates Ltd, the Structural and Geotechnical Engineer of the project. This paper is solely from construction point of view and the authors would like to express their gratitude to Siu Yin Wai & Associates Ltd regarding their concept of off-loading sequence of the temporary supports as well as their supply of design data and site measurement of the off-loading process. The technical paper regarding the detailed design of “The Spectacle Roof” will be prepared by Siu Yin Wai & Associates Ltd shortly.

HKIE TRANSACTIONS, 2018
VOL. 25, NO. 1, 29–43
https://doi.org/10.1080/1023697X.2017.1409663

Design and construction of long-span single-layer dome structures by direct analysis

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ABSTRACT
Long-span roofs are widely used worldwide as they provide large internal spaces without obstructions like columns. In designing long-span roofs, the traditional design method faces many difficulties, such as uncertainty in buckling effective length. The advanced second-order direct analysis (SODA) method for design shows and has many advantages for structural safety and cost saving. In this paper, the SODA considering P-Δ and P-δ effects as well as initial imperfections is proposed for designing of long-span roofs and the assumption of effective length is no longer required. The application of this concept of SODA to the design of practical structures appears to be new and unique, especially on the aspects of design at the construction stages. Key considerations for the construction of long-span structures by SODA are first reported. The planning of the lifting procedure, temporary support system (TSS) and off-loading sequences for load transfer from a TSS to permanent structure is guided by SODA such that an economic design and safe construction can be achieved. A constructed long-span single-layer roof structure in Macau is used to demonstrate the validity, practicality, accuracy and reliability of the proposed method and is taken as an example of successful joint work for advanced design by academicians and engineers in practice.

ARTICLE HISTORY
Received 13 March 2017
Accepted 14 November 2017

KEYWORDS
Second-order direct analysis; construction sequence; long-span structures; dome structures; off-loading analysis

1. Introduction

Long-span roof structures are widely constructed in stadia, shopping malls, public halls, warehouses, airport terminals and so on as they provide large internal spaces without obstructing structural supports like columns. The commonly used typologies of roof structures include single-layer grids, double- and multi-layer grids and their combinations. Long-span roofs generally experience large deflections and are sensitive to initial imperfections and patterned loads, especially for single-layer domes. The structural design complexity includes the fact that roof members cannot be clearly classified as beams or columns like their counterparts in conventional building structures; most steel design codes are for buildings made of columns and beams. Furthermore, the checking of snap-through or snap-back buckling is beyond the capacity of a traditional linear design method based on the effective length approach (ELM) due to the complex buckling mode involving large deflections.

In Hong Kong and the region such as Singapore, Macau, etc., the second-order direct analysis (SODA) method is quite commonly adopted in design offices for conventional structural design under static loads [1,2], performance-based seismic design [3], progressive collapse analysis, structural fire analysis [4] and so on. This method is known to reflect the true and ultimate structural behaviour of members and frames in the analysis stage more accurately, while the traditional ELM only gives approximate responses with the need to carry out additional stability checks in the design stage after analysis. The stability design check is not consistent with the analysis and it is based on an engineer's experience, which becomes unreliable for complex and uncommon structures with a complicated buckling mode. For instance, the value of effective length is not reliable to be determined for shallow domes susceptible to snap-through buckling. With consideration of P-Δ and P-δ effects, initial imperfections and other factors which affect strength, stability and stiffness such as joint behaviour, the assumption of effective length or K-factor required in the design stage can be completely discarded in SODA because the effects of instability have been automatically considered rationally and reliably in the equilibrium and stability checks in the analysis stage.

Although the SODA has been well researched [5–9] and its concept has been specified in many modern design codes such as EC3 [10], AISC-LRFD [11] and CoPHK [12], previous work mainly focused on the application of SODA in design stage for structures after completion, rather than in the construction stage. It

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