Measurement 74 (2015) 268–277

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Assessment of angular distortion of structures adjacent to a road embankment site

Tae-Hyung Kim [a,*], Kook-Han Kim [b], Young-Chul Choi [b,c]

[a] Department of Civil Engineering, Korea Maritime and Ocean Univ., 727, Taejong-ro, Yeongdo-Gu, Busan 606-791, Republic of Korea
[b] Naengjeong-Busan Construction Agency of the Korea Expressway Corporation, 805, DaewangPangyoro (239-1, Geumto-dong), Sujeong-gu, Seongnam-si, Gyeonggi-do 461-703, Republic of Korea
[c] Pavement & Material Research Division of Research Institute, Korea Expressway Corporation, 50-5, Sancheok-ri Dongtan-myeon, Hwaseong-si, Gyeonggi-do 445-812, Republic of Korea

ARTICLE INFO

Article history:
Received 27 January 2014
Received in revised form 4 June 2015
Accepted 9 June 2015
Available online 25 June 2015

Keywords:
Angular distortion
Differential settlement
Damage
Crack
Road embankment

ABSTRACT

Angular distortion caused by differential settlement critically influences the damage to and serviceability of a structure. The angular distortion criterion proposed by Bjerrum generally is used in practice. However, some measurements used in the field do not properly represent the angular distortion of a structure in a way that allows Bjerrum's criterion to be applied. This paper includes a discussion of using the measured data obtained from ground and structures near road embankment sites over deep soft soil. The data analysis revealed several problems, such as an insufficient number of measurement gauges, improper installation of gauges, and incorrect understanding of the angular distortion during data interpretation. An improved measurement method, called "relative displacement measurement," was suggested. The proposed method was demonstrated in the field. Compared to the previous measurement, this method provides more accurate measurement of the relative displacement between columns of the structure and better represents the angular distortion.

1. Introduction

Uniform settlement in soft soil generally does not affect the stability or serviceability of structures; in most cases, it is the differential settlement that causes structural and functional problems. For engineers who design structures, angular distortion (or the deflection ratio) is the major concern. In particular, the maximum angular distortion or deflection ratio is the key factor.

The settlement phenomenon of a base foundation, as shown in Fig. 1, can be expressed in several ways. In this figure, the base settlement contains marks showing the original locations (A–E) and the new locations (A′–E′) of the five points. The settlement (S_T) is perpendicularly deflected, and maximum settlement ($S_{T(max)}$) occurred at point B. Differential settlement (ΔS_T) is the difference in settlement between two points. As Fig. 1 depicts, the maximum differential settlement ($\Delta S_{T(max)}$) occurred between points B and E. Angular distortion (β) is a slope between two points, defined as ($\Delta S_{T(ij)}$) and l_{ij}. Relative deflection (Δ) is the movement from a straight line joining two reference points, and the deflection ratio (=curvature) is the ratio of the relative displacement of Δ/L. In most cases, angular distortion, rather than the deflection ratio, has been favored for reliably estimating the transformation of the differential settlement of the base foundation. Thus, many studies have been conducted in relation to angular distortion [3,9,14,17].

Angular distortion has been used in planning and construction management to reflect the effect of differential settlement on the damage to and serviceability of

* Corresponding author. Tel.: +82 51 410 4465.
E-mail address: kth67399@kmou.ac.kr (T.-H. Kim).

http://dx.doi.org/10.1016/j.measurement.2015.06.002
0263-2241/

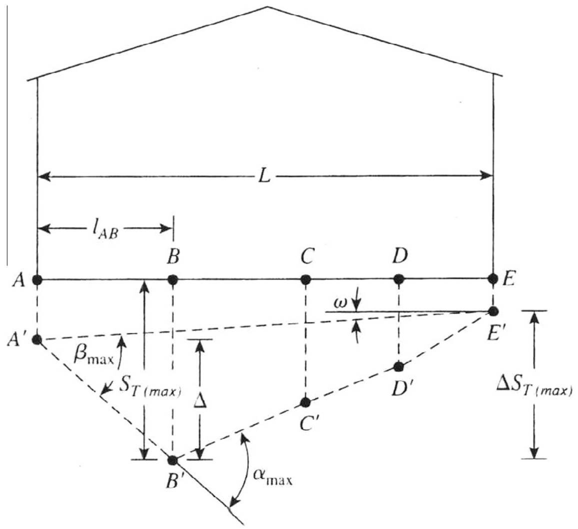

Fig. 1. Definitions of angular distortion and differential settlement [2].

structures [4]. The angular distortion is affected by various factors, such as the structure type, structure base, structure height, structure stiffness, settlement magnitude, and settlement velocity. Skempton and MacDonald [18] suggested that the angular distortion and the maximum differential settlement are 1/300 and 76 mm (isolated foundation in clay) and 76–127 mm (raft in clay). Currently, the allowable angular distortion criteria suggested by Bjerrum [3] are used in practice (Table 1), though these criteria only consider the type of structure. Bjerrum's based his criteria on those of Skempton and MacDonald, adding his own recommendations [14]. Although other studies have been conducted regarding angular distortion [8,13,19], they have not proposed criteria that differ much from Bjerrum's [3]. For instance, Gray [9] suggested 1.75 in. (44 mm) as the maximum differential settlement and 1/300 as the tolerable angular distortion. If the angular distortion exceeds 1/300, then visible cracks could appear in walls, and if it exceeds 1/150, damage to poles or beams could occur. The Engineer Manual of the U.S. Army Corps of Engineers [19] also suggested criteria for angular distortion that do not differ greatly from Bjerrum's criteria. The Engineer Manual makes a distinction by adding the elements of angular distortion that depend on the sagging and hogging of the sub material of the internal structure.

Table 1
Limiting angular distortion [1].

Category of potential damage	Angular distortion
Danger to machinery sensitive to settlement	1/750
Danger to frames with diagonals	1/600
Safe limit for no cracking of buildings	1/500
First cracking of panel walls	1/300
Difficulties with overhead cranes	1/300
Tilting of high rigid buildings becomes visible	1/250
Considerable cracking of panel and brick walls	1/150
Danger of structural damage to general buildings	1/150
Safe limit for flexible brick walls, L/H > 4[a]	1/150

[a] Safe limits include a factor of safety. H = Height of building.

Bjerrum's criteria are used to determine a potential damage of structure in many construction sites where structures are exposed to damage caused by differential settlement [5]. The most common damage is cracks on the walls. Building structures adjacent to excavation sites are very susceptible to damage [11,12]. Structures adjacent to road embankment sites, especially on soft ground, are also very susceptible to such damage because the behavior of soft ground significantly depends on the embankment construction process. The ground at the embankment site exhibits settlement and heaving behavior repeatedly due to the decrease and increase in excess pore water pressure induced by the staged fill placement over soft soil [6]. If the embankment is large and the soil is deep, the influence is more significant [10,20].

Generally, settlement pins and an inclinometer are used to evaluate the angular distortion of a structure located near a road embankment site. The settlement pins are installed on the surface of the ground near the structure or directly on the structure. The data obtained from two pins is divided by their length to yield the angular distortion. The inclinometer attaches to the wall of the structure to directly measure its angular distortion. While this measurement system is the most common method used in the field, it cannot properly present the structure's angular distortion caused by differential settlement. Consequently, the measurement gauges do not sufficiently detect the development of cracks in structures.

Therefore, this paper attempts to analyze the suitability of the field measurement system used in the application of angular distortion criteria for assessing the damage especially crack of structures near a road embankment that served as the site of the construction of an interchange. The data measured at the road expansion site were analyzed, shedding light on the limitations of the current measurement system and revealing suggestion for possible alternative. The alternative method as proposed as a result of this study will provide a solution for engineers who are faced with determination of the angular distortion in structure near embankment construction site on soft ground.

2. Field description and measurement results

2.1. Site description

The field site is an interchange of the Naengjeong–Busan road expansion construction section in the second branch of the Namhae Expressway (Fig. 2). Structures such as warehouses (B and C), a cattle shed (D) and a house (A) are adjacent to this site. Both the warehouses and the cattle shed have a combination of strip and mat foundations with a concrete slab. The walls are made of reinforced concrete in the lower part and panel in the upper part. The pillars are constructed of steel H-beams. The house is a masonry building.

The site is located in the area west of the Nakdong River, called the Nakdong River Delta, and thus, the soft soil is approximately 40 m deep (Fig. 3). This soil, which mostly consists of silty clay, is normally consolidated and has a specific gravity of 2.75, void ratio of 1.615, saturated unit