Available online at www.sciencedirect.com

SCIENCE @ DIRECT®

Construction and Building Materials 19 (2005) 746–754

Construction and Building MATERIALS

www.elsevier.com/locate/conbuildmat

Predicting the ultimate bending capacity of concrete beams from the "relaxation ratio" analysis of AE signals

Sabrina Colombo [a], M.C. Forde [b,*], I.G. Main [c], M. Shigeishi [d]

[a] Powell Tolner & Associates, 29 Red Lion Street, Chesham, Bucks HP5 1EJ, UK
[b] University of Edinburgh, School of Engineering and Electronics, King's Buildings, Edinburgh EH9 3JL, UK
[c] University of Edinburgh, School of GeoSciences, King's Buildings, Edinburgh EH9 3JN, UK
[d] Department of Civil Engineering, Kumamoto University, Kumamoto, Japan

Available online 26 July 2005

Abstract

This paper presents an alternative approach to the problem, based on "testing" the real structure rather than trying to model it. Experiments on reinforced concrete (RC) beams, representative of bridge beams, are described. The beams were loaded in cycles up to failure whilst recording the acoustic emissions (AE) generated. The analysis of the AE signals was then undertaken based on a proposed new parameter, named the "relaxation ratio". This quantifies the AE energy recorded during the unloading and loading phases of a cycle test and it showed a clear correlation with the bending failure load of the RC beams. A change in trend was noted when the load reached approximately the 45% of the ultimate bending load. The results appeared to be influenced by factors such as the concrete strength and loading rate and further work is needed to extend the results to full scale testing of bridge beams.
© 2005 Elsevier Ltd. All rights reserved.

Keywords: Concrete; Acoustic emission; AE energy; Relaxation ratio; Load capacity

1. Introduction

Bridges make up part of the asset of a country and their assessment and maintenance is a fundamental issue. The introduction of the 40 tonnes EU Directive in the UK has highlighted the matter even further [6]. For a long time, the assessment of a structure was considered a "special case" of the design and the first code that dealt directly with assessment dates back to 1990. Although studies have progressed, the majority of the existing codes assess the load carrying capacity of bridges by using theoretical methods and models.

Bridge engineering is not only about designing but also includes "looking after" and maintaining the service-life of bridges. After a period of relative neglect in the 1970s there was a growing awareness of the necessity to safeguard and maintain the stock of bridges as part of the national asset. The concern about environmental and sustainability issues, started in the mid 1980s. The introduction of the EU Directive which states that "bridges on principal routes, have to be capable of taking 40 tonne vehicles by 1 January 1999", highlighted this necessity even further. Before the mid-20th century, no analytical tools were available and the only way to assess the integrity of a bridge was based on visual inspection and intuitive judgement [12]. For a long time, the assessment was considered as a "special case" of the design and thus the same rules were applied. The "Assessment Code BD21/84" [1] represented a milestone in the start of introducing codes which dealt directly with bridge assessment and it was followed later on by the new protocol BD44, produced in 1990 [2]. Although these codes represent a huge improvement

* Corresponding author. Tel.: +131 650 5721; fax: +131 650 7167.
E-mail addresses: Sabrina.colombo@ed.ac.uk (S. Colombo), m.forde@ed.ac.uk (M.C. Forde), ian.main@ed.ac.uk (I.G. Main), shige@civil.kumamoto-u.ac.jp (M. Shigeishi).

0950-0618/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.conbuildmat.2005.06.004

for the assessment of bridge structures, they are mainly based on theoretical and modelling calculations and therefore always include a certain degree of uncertainty and the use of safety factors.

This paper describes a different approach that aims to predict the degree of damage and failure load of concrete beams by directly testing the structure. The final future aim would then be to implement this method in order to be applied to real bridge structures. The method herein proposed uses a newly developed type of acoustic emission (AE) data analysis, which utilises a newly defined parameter, named relaxation ratio [5]. This is based on the principle that the presence of AE energy during the unloading phase of an AE test is generally an indication of structural damage of the material and/or structure under study. The results of experiments on several reinforced concrete (RC) beams are described, the relaxation ratio is calculated and the results are discussed. The emerging trend of the values of the relaxation parameter seem able to provide an estimation of the bending failure load of the tested specimens, although some external factors (discussed later on) appeared to affect the results. The validity of the proposed method was finally validated by a comparison with the assessment criterion suggested by the Japanese Society for Nondestructive Inspections (JSNDI).

2. The relaxation ratio analysis

An AE test generally consists of several load cycles on the material or structure of interest. Each cycle normally includes a loading phase and an unloading phase. The initial idea that led to the development of this analysis derives from some observations made during the undertaking of some experiments. It was in fact noted that the AE activity recorded during the unloading phase of the cycling loading procedure was increasing as the damage on the beam was progressing. In fact, AE activity observed during the unloading process is generally an indication of structural instability [11,15]. This is consistent with the Kaiser effect for dilatant microcracks and implies that shear cracks do not form until near the macroscopic structural failure. While generally in an AE test, the activity generated during the unloading phase is neglected, the analysis presented here focuses on this particular activity.

A parallel can be drawn with earthquake sequences, recognised in seismology. Earthquakes seldom occur as isolated events, they are made up of *foreshock* and *aftershock* sequences which are closely associated with a larger event called the mainshock. A schematic illustration can be seen in Fig. 1. Aftershocks follow the mainshock and are linearly proportional to the area of the mainshock rupture. Aftershocks typically begin immediately after the mainshock over the entire rupture area and its surroundings, or are generally concentrated around the rupture perimeter or in locations where the mainshock has newly produced high concentrations of stress. Therefore, it can be said that aftershocks are a process of relaxing stress concentrations caused by the dynamic rupture of the mainshock. Foreshocks are smaller earthquakes that preceded the mainshock. They generally occur in the vicinity of the mainshock hypocentre and are probably a part of the nucleation process [13]. Keeping earthquake sequences in mind the failure of a specimen, or accumulated damage at the end of a load cycle, can be considered as the mainshock. The foreshocks and aftershocks can be seen as the acoustic emissions generated, respectively, during the loading and unloading phases.

In the light of these preliminary observations, a "relaxation ratio" is proposed to quantify and compare the AE activity during the loading and unloading phases. Previous experiments have shown [4] that the AE energy is an effective parameter to describe the structural damage of a beam, therefore the relaxation ratio is expressed in terms of energy and defined as:

$$\textit{Relaxation ratio} = \textit{average energy during unloading} / \textit{average energy during loading phase},$$

where the average energy is calculated as the cumulative energy recorded for each phase divided by the number of recorded hits. The use of the average energy overcame the problem of the different time duration of the varied cycles that could affect the results. A relaxation ratio greater than one implies that the average energy recorded during the unloading cycle is higher than the

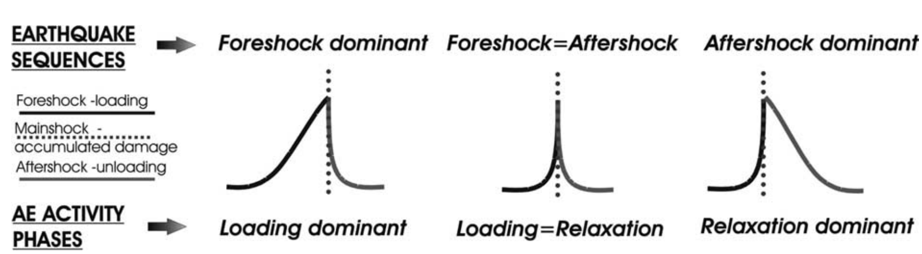

Fig. 1. Schematic representation of earthquake sequences and AE activity phases. Each individual diagram shows the number of events, as a function of time, with the vertical dotted line being the time of the mainshock.

دریافت فوری ← متن کامل مقاله

ISIArticles
مرجع مقالات تخصصی ایران

- ✓ امکان دانلود نسخه تمام متن مقالات انگلیسی
- ✓ امکان دانلود نسخه ترجمه شده مقالات
- ✓ پذیرش سفارش ترجمه تخصصی
- ✓ امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- ✓ امکان دانلود رایگان ۲ صفحه اول هر مقاله
- ✓ امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- ✓ دانلود فوری مقاله پس از پرداخت آنلاین
- ✓ پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات