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Hurst exponent footprints from activities on a large structural system

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ABSTRACT

This paper presents Hurst exponent footprints from pseudo-dynamic measurements of significantly varied activities on a damaged bridge structure during rehabilitation through continuous monitoring. The system is interesting due to associated uncertainty in large-scale structures and significant presence of human intervention arising from fundamentally different processes. Investigations into the variation of computed Hurst exponents on time series of limited lengths are carried out in this regard. The Hurst exponents are compared with respect to specific events during the rehabilitation, as well as with the data collection locations. The variations of local Hurst exponents about the values computed for each activity are presented. The scaling of Hurst exponents for different activities is also investigated; these are representative of the extent of multifractality for each event. The extent of multifractality is assessed along with its source and time dependency.

1. Introduction

The application of the Hurst exponent has gained considerable attention in recent times [1–5] in very disparate fields. The popularity of such application is not just related to the dependency on output data and the ease of application, but is often driven by the fundamental complexity in the nature of the application or complexity in the actual data. Investigations into the interpretation of computed Hurst exponents have already generated a significant body of research [6–9] and still continue to do so. On the other hand, the methodology of computing or estimating the Hurst exponent [10–12], and the properties of the Hurst exponent [13], along with related links to the multifractality of systems [14], remains extremely topical.

Independent of the varied methodology or interpretation, estimated Hurst exponent values have been observed to have a potential to become a powerful tool for the detection and estimation of features of interest from time series data. In this regard, applications to financial markets [15,16], oil prices [17], hydrology [18] and earthquakes [19] have been reported and there exists an obvious popularity of applied problems that are related to the financial market. Estimations of future values [20,21] and rapid changes [22–24], detection of influence of variables [25] or prediction of relationships between variables [26,27] have been studied in this regard. Most of the applications or detections deal with natural systems or financial systems, where the governing laws for the entire system are often too complex to model. A Hurst exponent based approach is extremely useful when a wide range of underlying activities exist within a system over a measured length of time, but the measurement from the system is not suitable for Fourier analysis based [28–30] or time–frequency analysis based [31–36] (wavelets, S-transform, Hilbert–Huang transform, etc.) methods. Fourier based approaches are not very useful

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Fig. 1. Apparent damage due to impact. The true damage is more extensive than this in depth and breadth.

for data sampled at a very low rate [37] or when the contribution of certain frequencies is dominant only within a short period of time due to the integration being carried out over the entire time domain. Windowed Fourier transforms, or, in general, time–frequency type analyses like wavelets are better for applications, but problems related to low sampling rate [38], uneven sampling rate [39] and masking [40] remain. The Hurst exponent based approach, even when the exponents may not have a strict interpretation, can have significant advantages for monitoring activities when the collected data are not well sampled and are available without the knowledge of the system.

This paper investigates a system in which varied natural and human activities on a large structure over a significant period of time generate the time series. The rehabilitation of an impact damaged full-scale bridge structure was continuously monitored at multiple locations in this regard. The activities during the rehabilitation process were fundamentally different, and significant uncertainties related to the loading process were associated with the system, including human factors. The interaction can be viewed as that between planned human activities and designed systems exposed to environmental variables. The Hurst exponent signature related to such activities is investigated over time and at multiple locations. The potential of using the Hurst exponent as a marker for changing activities or for structural health monitoring is investigated.

The rest of the paper is organised as follows. Section 2 describes the system and the data obtained from continuous monitoring; Section 3 briefly presents the methodology behind the estimation of Hurst exponent; Section 4 presents the results where the variation of Hurst exponents based on events and on the data collection location is investigated, along with their variability and discussions on the implications of the results; and Section 5 provides the conclusions of this investigation.

2. Experimental details and description of data

The data were obtained from the emergency rehabilitation of an impact damaged bridge over a National Primary road of Ireland. The damage was due to an impact to the soffit from a low-loader carrying an excavator passing underneath the bridge. The two-span continuous slab—girder bridge comprises six precast prestressed U8 type concrete beams connected by a continuity diaphragm. The reinforced concrete piers are integral to the deck and the ends of the bridge are simply supported on reinforced concrete abutments. Fig. 1 presents a close-up photograph of this damage. An unknown redistribution of stresses took place following the impact. Hammer tapping and acoustic emission tests established that the true damage was more extensive than the apparently observed damage.

The rehabilitation was carried out by preloading the bridge to 120 t over the carriageway and at the two ends of the damage using concrete blocks at 20 t increments. Hydrodemolition and removal of damaged concrete was carried out next. The preloading removed some of the tensile prestress from the top and also helped in developing some prestrain at the location of damage. It also helped in avoiding damage due to sudden release of locked-in strains from the damaged concrete. Following hydrodemolition, rapid-hardening and high-strength repair material was applied to the damaged region and the preloads were removed after the hardening of repair material. The removal of preload was expected to reintroduce some amount of lost prestress in the repaired zone. The structure was monitored throughout the rehabilitation process using pseudo-dynamic measurements of one sample every minute using vibrating wire strain gauges. Nineteen gauges were instrumented on the damaged bridge at five locations, referred to as monitoring points (MPs). The low sampling frequency is related to the practical implementation of measurements at large scale. The choice is guided by the sampling resolution, robustness against physical activities, exposure to environmental and mechanical conditions, and accuracy of collected data. A higher sampling frequency usually corresponds to small gauges that are easily affected by small electrical, mechanical and environmental fluctuations and lead to a lower quality of data with associated noise and fluctuations that are very difficult to estimate. From an implementation perspective, the connection with the large structure also is not very good due to the small size of the gauges and the rough surface of large structures. Additionally, these gauges with higher sampling frequency are