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BS 5228 : THE PREDICTION OF NOISE FROM CONSTRUCTION SITES

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1. INTRODUCTION

Earlier this year, the Acoustics Research Unit at the University of Liverpool hosted a one-day workshop, the main theme of which was BS 5228, with an emphasis on the predictive aspects of the standard. This event was part of a current research project in the unit, investigating the prediction of environmental noise from construction and open site industrial activities. This project is funded by EPSRC.

In this paper, we :-

- give a brief outline of the objectives and format of the workshop;
- discuss the main issues raised, in the context of the aims of the research project, and
- summarise these aims, with a brief description of the general approach to the problem.

2. THE WORKSHOP

The objectives of the workshop were to :-

- provide a forum for researchers in environmental noise propagation and practitioners involved with the application of BS 5228 to the prediction and control of noise from construction and open industrial sites, where they were invited to discuss and/or comment on the latest edition of the standard, and to relate their own experiences and concerns with respect to its use;
- introduce the context and aims of the research programme to the various user groups present, through a structured series of short presentations.

The presentations were organised in 4 sessions :-

- a review of the history of BS 5228, and a summary of the revisions in the second edition, published earlier this year;
- some views on current usage of the standard, particularly of the methods (described in Annex D of the present standard) for the estimation of noise from sites, and the difficulties facing developers and contractors in attempting to use them in the context of designing and planning construction projects (as recommended in sections 9.1 and 9.2 of the standard);
- problems with accuracy in the prediction of environmental noise propagation generally;
- brief descriptions of alternative, non-deterministic, modelling methodologies: stochastic systems and artificial neural systems (ANS), which have been applied successfully to prediction problems in other areas of construction project management; these methods may provide a less demanding approach, during the pre-contract period, to the prediction of expected noise emissions from construction sites than does rigorous application of the standard, deterministic, methods.

Each session was followed by questions and views from the floor. The main points raised are addressed in the following sections, where they relate to the motivation of the project: i.e. the approach to the control of construction site noise recommended in sections 9.1 and 9.2, and the predictive methods described in Annex D of the standard [1].

A full report on the workshop, in the form of expanded papers on the presentations, is to be published [2]. Another workshop, to report on this research work and to discuss any other relevant developments, is proposed in 1999.

3. CURRENT USAGE OF BS 5228 METHODOLOGY

Currently, the BS 5228 methodology is used mainly for assessment of proposed open industrial sites (mineral extraction, landfill etc.), and larger long-term construction sites (typically for major infrastructure projects). In these situations, noise predictions are required as part of an environmental impact assessment. In section 9, the standard recommends that the design and planning of any project should reflect an intention to minimise levels of site noise as far as is practicable. However, opinion is divided as to whether noise assessment is necessary for construction sites generally, and use of the estimation methods tends to be limited to isolated situations, where a specific operation known to cause problems is proposed, or retrospectively, to support one or other side in a dispute.

There are several possible reasons for the apparent lack of enthusiasm for prediction in the general construction case. A common argument is that people are, or may be, more tolerant of construction site noise because of its short duration, and/or because of some perceived benefit from the development. However, this may be no more than a convenient interpretation of statistics. The relatively small number of complaints does not necessarily imply that people find construction noise less intrusive: it may indicate instead that people feel that there is no point in complaining, since, by the time anything is done about it, those responsible will have finished their work and disappeared.

There is some evidence of an increase in complaints about construction noise. Since these complaints are generally directed at local authorities, they are becoming more inclined to impose relevant restrictions as conditions on planning approval. Bassett [3] gives examples and discusses some of the problems in estimating likely construction noise levels for planning approval negotiations. Stubbs *et al* [4] present a case study illustrating a contractor's response to the inclusion of noise criteria in tender documentation, and the assumptions and simplification necessary to cope with this requirement using the BS 5228 methods.

Compliance with any restrictions imposed as conditions on planning approval will force developers, and contractors tendering for the work, to respond positively to the problems of noise estimation and control. Ideally, as developers and contractors become more aware of the need to reduce general noise levels in our environment, the proactive approach of the standard will become widespread practice: this requires consideration of the noise level implications (i.e. the processes involved) inherent in the design as it is developed, and early consultation with the local authority to ascertain what, if any, limits or restrictions are likely to be applied to the proposed work. Either way, by force or choice, noise predictions will have to be made when those elements of the project which eventually determine the relevant noise source data are only coarsely defined.

Even if the general necessity for noise assessment of construction sites ceases to be at issue, there remain factors which hinder noise assessment during pre-contract activities, and discourage use of the BS 5228 methods :-

- there is no explicit guidance in the standard on noise limits or working restrictions: construction work takes place in a wide variety of environments, and it is not possible to define succinctly a set of constraints that will be applicable to every scenario; for instance: night and weekend operation may be more appropriate for a site in an office district, whereas it would be unacceptable in residential or mixed areas, except in emergency; this is an extreme but realistic example, which illustrates the flexibility required of developers, contractors and local authorities in agreeing the best approach to noise control in a particular situation, which should be judged on it own unique combination of circumstances, rather than constrained by a more or less arbitrary set of rules; the problem is that the proponents of the project have no baseline figures to guide their proposals;
- the costs both of making the assessment, and of consequent preventative measures, may be a strong inhibiting

factor, particularly if the local authority does not exercise its power to impose constraints;
- the difficulty and uncertainty in applying the methodology in this situation, due to the complexity of the problem and the coarse granularity of the data definition; the consequent assumptions and simplifications necessary to carry out the exercise will generate results with unquantifiable errors; this leads to a lack of confidence in the validity of the predictions, and doubt in the necessity for any mitigation measures based upon them.

Although regulatory and commercial considerations are likely to have an important influence, they are beyond the immediate scope of this project, which addresses the last of these factors.

4. THE DETERMINISTIC APPROACH TO PREDICTION

The equations and procedures used in the BS 5228 methodology constitute a deterministic model: the output depends entirely upon the explicit data values input by the user, and no allowance is made for any possible variations in these values due to external, uncontrollable, influences or events. The output accuracy of such a model is then assumed to depend directly upon that of the input data, and the same input will always yield the same output. The effects of using inaccurate data in the model cannot be assessed with any confidence, since there is no measure of the inaccuracy.

Like any model, it is incomplete: the real-world complexity of most situations makes exact representation in a deterministic model virtually impossible. During a construction project, there are always likely to be random events or unforeseen conditions which cause delays and/or additional, noisy, work: typical examples, arising from inadequate ground information are :-
- breaking out hard spots, excavating soft spots, filling additional excavations and voids;
- pumping excess ground water;
- dealing with unmarked buried power cables, gas or water pipes.

Note that a ground survey, usually based upon boreholes, is a sampling procedure: the ground structure and content between sampling points is assumed from the information contained in the samples, which need not be too far apart to miss something substantial. Clearly, the probability of the assumptions being correct increases with the number of samples taken, but then so does the cost of the survey. Such problems are, hopefully, the exception rather than the rule, and attempting to model them deterministically will distort and invalidate the model.

There are other phenomena whose effects may be understood theoretically, but are in themselves too complex to be modelled deterministically. Meteorological conditions are an obvious example, notorious for their apparent unpredictability, although (some of) their effects can be expressed reasonably in analytic formulae. A less obvious, though possibly more influential, example is noise source directivity: while it may be possible to define the range of operation of an item of mobile plant for a specific period with reasonable accuracy, the actual movement and orientation of the machine within that range will be essentially random. Although measurement of L_{Aeq} under (physically) simulated conditions for a representative period would allow for this variation, it will be valid only in the direction of the measurement station. Values measured at other points around the simulation may be different, and no simulation will be able to replicate what actually happens on the day. Effects of source directivity and meteorological conditions are both specifically excluded from the scope of the standard model. There is also continuing research into the effects on sound propagation of factors such as atmospheric absorption, ground roughness and cover, and screening.

Some of these factors are generally regarded as marginal in their influence, or significant only at greater distances. Some may account for anomalous discrepancies between recorded measurements and predictions made under the optimum conditions detailed below. The standard model may be improved by incorporating relevant adjustments or equations where required, particularly the results of recent and current research as they become available. Other

(British and international) standards, codes of practice etc. dealing with environmental noise propagation may include relevant items: for instance, qualitative factors such as the tonal adjustment in BS 4142 [5]. Nonetheless, use of the model as it stands is appropriate, provided the following optimum conditions are satisfied :-

- accurate source sound power or pressure levels, or activity L_{Aeq} values, are obtained by measurement of actual plant to be used, under similar conditions over a representative period (as recommended in Annex D of the standard);
- operational locations/ranges are known to a reasonable degree of accuracy;
- periods of operation are known to a reasonable degree of accuracy;
- the propagation environment is accurately mapped;
- all possible noise-generating activities and propagation paths are taken into account;
- screening effects are calculated using a frequency-dependent model: this requires octave-band spectra for noise sources and performance data for particular barriers.

Under these conditions, the model should generate fairly reliable results.

Application to Permanent Sites

Generally, this seems to be the case with open industrial sites. which are relatively simple to assess :-

- the daily work and traffic patterns are more or less regular and long-term, and will have been established before a planning application is made;
- the number of activities and different plant items involved is relatively small;
- the plant to be used will be known more or less at the outset, and it should be possible to obtain the relevant source noise data for these at the time it is required.

When discrepancies between predictions and recorded measurements do occur in this context, they are likely to be due to one or more of the marginal factors cited above. Such sites tend to be in rural areas, with points of interest at greater distances: weather and atmospheric influences, and possibly ground effects, will then be more important. Augmentation of the model as discussed above will probably reduce the occurrence of such errors.

Application to Transient Sites

Construction sites, on the other hand, although involving some similar activities and plant, pose quite a different problem :-

- the daily work and traffic patterns change as the contract progresses, with random events such as material deliveries, and several concurrent or overlapping activities – there is far more to be assessed, much of which is unpredictable or variable;
- when planning approval negotiations start, only the architectural design is likely to be advanced – the structural engineering design, which probably accounts for most of the noisiest activities, will only have been developed sufficiently for feasibility and budget costing; the only timing data will be a site possesion date and latest acceptable completion or maximum length of contract period; no real measurement (of the work) will have been done, and the kind of plant required will be known only in general terms: the developer will naturally aim to keep development costs at a minimum until at least outline planning approval has been granted;
- no construction programme or method statement will exist until the contractors prepare their tenders, and even then the definition will be relatively coarse: the programme activities will be aggregated in terms of work elements significant to the project, the timescale defined in steps of 1 week, or even 1 month on very large projects, rather than 1 day as in the final contract form; the method statement will be an informal description of the proposed work sequence, highlighting any special processes or measures, and the site layout provisional;
- even at the tender stage, much of the plant schedule will be notional: most, if not all, of the work will be subcontracted, with subcontractors responsible for providing much of the plant - notably earth-moving machinery; longer-term items, such as tower-cranes, hoists and fork-lifts, will be hired, and thus subject to availability.

Under these circumstances, any assessment made during the design period will require assumptions and simplifications so gross as to effectively invalidate any strictly deterministic model. To obtain the data input requirements for the standard methods and apply them in a sufficiently rigorous way, the developer would have to invest substantially more than at present, in the employment of noise consultants and in an extended design phase based on, possibly repeated, iterations through a 'design - measure - plan - assess' cycle. Such a work pattern would preempt the main contractor's natural roles of site organisation and construction planning: this is in the interest of neither client nor contractor, since it would remove a key element from the tender evaluation process, whereby the competence of the tenderers can be assessed [6]. The likelier outcome is that the developer will agree in principle to the local authority's requirements, without any real validation of their practicality, and will pass on the responsibility for compliance to contractors, by including these requirements as contract conditions.

During the tender period, although the relevant data is considerably more refined, it is still somewhat coarser than required for reliable deterministic prediction, lacking particularly the precise noise source data. Given the time constraints on tender preparation, and the considerable investment sustained by contractors in bidding for contracts, it would be unreasonable to expect them to undertake the data collection and preparation necessary for full application of the deterministic model. To simplify the task for the limited time available, it will be necessary to make assumptions about what are the noisier activities - there is some consensus that generally the various groundworks are the most likely to cause disturbance, but this should perhaps be verified. The relevant part of the construction programme would have to be refined to show activities at the granularity found in annex C of the present standard, which contains the source values the contractor would probably have to use. (This elaboration of the programme would probably be more detailed than the usual final form, which is normally developed after the contract has been awarded.) Even with this preparation, the contractor would be faced with a formidable amount of work to make a proper assessment, but that would be wasted effort. The problem is that use of the source noise data given in annex C of the standard effectively invalidates the model: the standard advises that they be used with caution, since most of the data antecedes EC noise limits. Even if the data were thoroughly updated, it would have to be maintained regularly to be relevant, and in any event each value can only be representative of a range of possible values. It it thus impossible to know whether predictions obtained in this way are accurate, except by direct measurement of the actual work: any correspondence between predicted and measured values will be coincidental.

However, contractors have had to make predictions, presumably using the standard model in an abbreviated way, since there are no other methods readily available, and possibly employing noise consultants to assist in the exercise, and to monitor noise levels during the ensuing contract. The data from such assessments (input data, predicted levels, and corresponding measured levels) will be useful for statistical (and "neural") analysis in the development of alternative methods and their validation.

In terms of data definition (granularity), there is, then, a significant mismatch between the requirements of a deterministic model (as listed above) and the data available for early prediction during the design and construction planning activities. The data aggregates dealt with in the early stages of the project contain the detailed operational data only as implied ranges of potential values: the actual values which occur are resolved by a chain of contractual and operational decisions. There is a clear need for a non-deterministic model which can operate on the aggregated data to generate predictions with associated confidence limits, such as a stochastic model.

5. ALTERNATIVE APPROACHES TO PREDICTION

To see how alternative approaches to the problem may be used, some further discussion of the data which describes the deterministic model will be helpful. Among this data are some items which can be determined at any time, once a site has been identified for development :-

- the locations of noise-sensitive premises relative to the site, and associated ambient noise-levels for appropriate periods;
- the geometry and acoustic characteristics of the terrain between the site and points of interest.

This data is dependent upon the environment, and once determined, its granularity is not subject to change: i.e. it is always in the form required for the deterministic model, although specific values may be altered by events in the environment, beyond the scope or control of the project. Thus it is essentially the same kind of data, at whatever stage of the project prediction is required. Theoretically, there is no need for this data to be problematic for early prediction: it simply needs to be collected.

On the other hand, the noise-source data (noise-levels and other characteristics, locations, modes and periods of operation), and the changing geometry and acoustic characteristics of the site, are dependent mainly upon the project itself. The value of each item is ultimately determined by a particular sequence of decisions taken at various stages during the progress of the project, and/or random events and processes which are external to the model. At the beginning, the required data is highly aggregated (or "lumped"): it is implicit, but undefined, in the analysis of the building requirements specification and the site and ground surveys used to make the decision to develop a specific site in a specific way. Each datum has a distribution of possible values with a mean value and variance: the actual value realised when some building operation is carried out will be effectively a random sample from this range. As successive decisions in the relevant sequence are made, the granularity of the data is refined to some extent, and the potential for variation in each datum is reduced. Some of these decisions will be virtually random, since they will be based upon a set of conditions prevailing at that time, some of which will be determined by external events. The last decision in the sequence determines exactly when, where and with what specific machines a particular activity occurs, and may be based upon some random external event (such as the unforeseen inability of a plant hire company to supply the required machine, and consequent offer of something more powerful at the same price). The states (values) of the site geometry and acoustic characteristics are determined by all the operations carried out prior to this one: these states may change as a result of this activity.

Stochastic Models

The essence of the preceding discussion is that the BS 5228 model includes several variables which are effectively unpredictable, since they will be determined, at least in part, by processes or events outside the system. In simulation models, such (exogenous) variables are usually represented as stochastic processes, i.e. by random variables generated from a distribution established from observed data or theoretical considerations [7]. Complex deterministic processes can be aggregated and similarly represented, with adequate results, in order to simplify the model and reduce computing overhead. The stochastic approach also facilitates the inclusion of influences not normally considered in a noise model: for instance, it may be possible to use the sample density of the ground survey to assess the probability of unforeseen obstructions.

A stochastic model may be developed from a deterministic model in stages. The deterministic model is used for sensitivity analysis, by making several runs with various parameter values, to identify which parameters are non-critical, and so need not be represented stochastically. It may also be used to facilitate validation, which can be difficult when there are likely to be many stochastic variables, as is the case here. Exogenous variables are treated deterministically by setting them at mean values, to test structural assumptions in the model before introducing distributions.

The stochastic approach is the principal alternative under investigation in this project. It is a well established technique, as a feature of computer simulation, for dealing with complexity in operations research, particularly where mathematical analysis is difficult. As far as prediction is concerned, it has the distinct advantage of enabling the provision of accompanying confidence estimates. The considerable number of random factors identified in the above discussion suggest that its application here is indeed appropriate.

Artificial Neural Systems

Although the idea of neural processing occurred at about the same time as the appearance of digital computers (the late 1940s), research in ANS technology has only spread significantly beyond its origin in neurology since the early 1980s [8]. The general public perception of neural networks is still perhaps of something esoteric and mysterious: of the topics presented at the workshop, this provoked the most questions. The possibility of their application to this problem is an addendum to the original project, and is under consideration at present.

There are several quite different kinds of ANS architectures, some of which have been used with success in various prediction and optimisation problems, including acoustic applications and construction project management. They also provide an alternative approach to expert system development, which eliminates the need for thelarge number of rules necessary to drive a conventional expert system [9]. The need to reduce the amount of explicit data the user must provide for prediction suggests that an expert system component may be useful to the implementation of the model.

Other possible uses include the inverse (optimisation) problem which perhaps better represents what the contractor is likely to have to deal with: given a prescribed set of noise limits, to find the best (least expensive) working methods and programme that ensure compliance.

6. THE PROJECT

The research programme is concerned specifically with those aspects of the standard emphasised in section 2: the preventative approach to control of site noise emissions by careful project design and planning, informed by early consultation with local authorities and noise levels estimated using the given methodology. It addresses the limited current use of these (or any) methods for prediction of expected noise levels from construction sites.

In the context of a complex time-variant and mobile multi-source noise system such as a construction site, deterministic methods such as those described in Annex D of the standard are laborious to apply rigorously, requiring a large amount of detailed and accurate operational data, and many calculations. In the pre-contract phase of a construction project, when the design and initial planning activities occur, the aggregation of available data, and the short time in which assessment may be required, force assumptions and simplifications which will significantly and unquantifiably compromise the accuracy, and thus the reliability, of predictions obtained using deterministic methods.

The aim of the project is the development of non-deterministic prediction methodologies which can operate on the aggregated forms to which the relevant data is restricted during the pre-contract phases, to generate approximate results with associated confidence estimates. It is not expected that accurate predictions can be made with anything less than a fully resolved data set, but, given the limited data availability, that it will be more useful to have quantified error margins than the hit or miss results likely to be generated by inappropriate application of deterministic methods to inadequate data.

The approach to the problem is through computer modelling and simulation. The starting point is a deterministic model implementing the BS 5228 methods, designed to enable both assessment of the standard model under various conditions, and development of the non-deterministic models within the same framework.

Operations to be performed on the standard model include :-

- comparative analysis of predictions obtained using the methods as described in the standard, including the

varying quality of noise source data;
- analysis of the effects of substitution and/or addition of predictive elements developed in recent research, and from other standards and codes of practice;
- sensitivity analysis and validation for the development of alternative models.

The computer modelling approach implies a comprehensive analysis, not only of the data explicitly involved in the noise modelling problem, but also of construction project management and its interaction with the external world, to identify the factors which generate or may influence the data. Of particular interest is how the noise modelling data can be extracted from relevant project and external data, and the derivation of mappings between the various levels of data aggregation.

The statistical aspect of the approach requires the acquisition of a large amount of data. Apart from direct measurement of construction activities, which is necessarily limited by time and budget, practitioners (principally consultants, but also contractors and local authorities) are seen as the main possible sources for historical data.

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