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A USER-FRIENDLY PROGRAM FOR THE DETERMINATION OF THE PARAMETERS OF A COMPLEX PLASTICITY MODEL

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ABSTRACT

Sophisticated mechanical constitutive models are increasingly used for numerical simulations of industrial structures. The complexity of such models often prohibits direct and immediate determination of the material parameters involved from experiments. This has generated a need for computer programs dedicated to this specific purpose.

A number of such programs have been developed. They all rely on the same basic, well-established principles. They consider an "error function" which is the sum of the squares of the "distance" between the experimental results and the predictions of the model, for specific values of its parameters. The "optimum" parameters are defined as those minimizing this error function. Since the model predictions are generally regular functions of the model parameters, this minimization is achieved by applying a Newton method to the search of the zero(s) of the gradient of the error function. This requires knowledge of the first and second derivatives of the model predictions with respect to the model parameters.

Thus from a theoretical point of view, such programs do not raise any particular issue. From the practical point of view, however, many problems arise. Indeed most programs are general in that they apply to any model and any kind of experimental data; the user must provide the relation expressing the model predictions in terms of the material parameters in the form of some EXTERNAL subroutine. There are several drawbacks to such generality.

First, the optimization algorithm must be fit to cases where the relation just mentioned can only be specified numerically. Numerical differentiation is then necessary to estimate its first and second derivatives. Convergence of the algorithm may then be problematic and require careful choice of the values of the parameters controlling it, so that numerical expertise is required from the user.

Another drawback is that expertise is again required from the user from the physical point of view, to judge the soundness of the results. This is due to the general lack of uniqueness of solutions of nonlinear optimization problems. It frequently occurs for

instance that the program finds that some set of material parameters makes the error function stationary simply because these parameters are in a range where they have no influence upon the model predictions.

In the present paper, we propose to follow a somewhat different avenue in which a specific program is developed for each model (or class of models) envisaged. The price to pay is a substantially larger programming effort. The benefit is that the numerical and physical expertise required may then be incorporated into the program instead of being demanded from the user.

As a typical example, we shall present a program which determines the material parameters of a plasticity model incorporating two kinematic variables and three parameters. The first variable is subject only to hardening while the second is subject to both hardening and strain-controlled relaxation. In the simplest version, all parameters are constant and the model reduces to that of Armstrong and Frederick. In a refined version, the parameter governing hardening of the first variable becomes a function of the equivalent cumulated strain. The advantage of such a formulation is that the model then becomes able to reproduce any arbitrary stress-strain curve in simple tension. The data which must be provided by the user consist of the stress-strain curve in simple tension plus the cyclic curves if available.

The need for numerical expertise of the user is eliminated by taking advantage of the simplicity of the experimental situations considered here by calculating the function expressing the model predictions in terms of the material parameters, together with its first and second derivatives, analytically instead of just numerically. The convergence of the Newton algorithm used to minimize the error function is then optimal, and no longer requires the introduction of adequate control parameters.

In order to reduce the need for physical expertise of the user, the optimization process is performed in several steps. In the case of the simpler Armstrong-Frederick model, a rough estimate of the parameters is first deduced from the beginning and end of the stress-strain curve in simple tension, plus the different hardening slopes in tension and compression if cyclic curves are provided. In a second step, one concentrates on those parameters which can be determined through linear optimization and evaluates them in this way, the other ones being fixed. In a final step, all parameters are determined simultaneously through nonlinear optimization.

The advantages in this procedure are two-fold. First, the material parameters obtained are always physically reasonable, because the first estimate is based on such elementary considerations that is cannot yield absurd values, and the variations of parameters resulting from the subsequent steps are carefully controlled, these steps being eliminated if these variations are too large. Second, the procedure maximizes the chances of the final nonlinear optimization to converge, since it starts from values of the material parameters which are already close to the final solution.

In the case of the more complex model in which the parameter governing hardening of the first variable becomes a function of the equivalent cumulated strain, extra care is taken. First, prior to allowing this function to vary, one performs a full optimization based on the assumption that it is constant. Second, a smoothing procedure is finally proposed in order to eliminate spurious, meaningless oscillations of the function found.

Experience shows that the program thus developed allows even inexperienced users to easily determine material parameters for the two versions of the model envisaged.