PIPING LAYOUT OPTIMIZATION

USING

CAD AND MATHEMATICAL PROGRAMMING

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Abstract
Optimal branching and pipe diameters distribution are sought using a mixed combination of a graphic definition of possible nodes and paths and a mathematical programming technique. The main objective is to obtain a low cost solution with constraints on flows and pressures at supply points. The numerical definition of possible layouts is made with the manipulation of a computer aided drawing commercial package. The network minimization is performed with a minimum path algorithm applied to the design space with practical and manufacturing constraints.

1. OPTIMIZATION AND ENGINEERING

Engineering Optimization is a very interesting discipline within the Engineering field. The term Optimization is somewhat redundant when connected with the word Engineering. The latter has the already the implicit meaning of obtaining the best solutions. However, most of the engineering techniques are studied and derived to obtain a solution for a problem without a specific criteria to choose the best solution. It is clear that within the pool of solutions there are some better than others and when other factors, besides the technical ones, are considered, like cost or time then, it is justifiable to consider the term Optimization (F. Hiller et al, 1982).

It is in the human nature the intention to do better than the last time. That was the genesis of Operations Research or Engineering Optimization. The situation that originated

this discipline was during the second world war where resources were limited in face of the demands. The objectives of this field is the resource allocation in an effective manner. The resources may be classified as labor, energy, money and materials. Since these have market value the measurement of a good allocation is a low cost. This becomes especially significant for civil engineers that are generally involved in large-scale public-works projects (E. Grant et al, 1982).

What Optimization materializes for each problem is the goal or objective in terms of an analytical function that translates a profit, a cost or a benefit. Since most of the time there are constraints that bound the domain of possible solutions these are also expressed in mathematical terms. Once the problem is formulated there are optimization techniques that will produce the optimum solution. This design will satisfy the constraints of the problem and at the same time maximize the profit or minimize the cost. The mathematical model derived from the real problem is very important for the respective definition and solution. Choosing the adequate optimization technique is also a decisive step to obtain a good solution.

It is not an exact engineering science and sometimes there is even uncertainty about the determination of an optimal solution. Most of the optimization techniques are based on numerical methods and care should be used when applying them (G. V. Reklaitis et al, 1983). Besides these facts there is always a difficulty in defining a suitable model for the problem. This model can not be too simple, because it will produce a defective solution, and can not be too complicated taking the chances of creating an impossible problem. Some researchers classify this discipline as an art more than engineering. For all these reasons it is expected a certain degree of experience and knowledge from the part of the analyst if rapid and accurate results are expected.

2. PROBLEM FORMULATION

Design of building piping layouts is an area where adequate problem formulation and suitable mathematical

programming technique may provide a proper methodology to search for a better solution. The design problem characteristics are translated into mathematical expressions composed by an objective function and a set of constraints.

The variables of these expressions are the quantities allowed to vary during the design and, thus, are called design variables. The objective function is the value to be minimized taking into account that it generally expresses the cost of the design as a consequence of the design variables, like the sum of pipes costs. The constraints are the functions that represent limitations used in design like maximum pipe velocities or flow demands.

A typical optimization problem will be presented as

$$\text{minimize} \quad f(\underline{x}), \; x_j = 1,n$$

subject to

$$g_i(\underline{x}) \leq 0, \; i=1,m$$

where x_j are the design variables, $f(\underline{x})$ is the objective function and $g_i(\underline{x})$ are the constraints. These functions may be linear or nonlinear and, consequently, the problem may be stated as linear, if all expressions are linear, and nonlinear otherwise.

3. BUILDING PIPING LAYOUT

Design variables may be the pipe diameters that are discrete variables. The objective function will be the sum of the pipe costs expressed as a nonlinear function of the design variables. The constraints will guarantee that demands are met, that velocities and nodal pressures will stay in a fixed interval and that there will be flow continuity at each node (R. Delebecque, 1969).

Taking into account that the building plan exists in a CAD storage it will possible to define all possible layouts for the pipe network, The location of node demands and source node are given. The positions of possible nodes for pipe branching or change of pipe direction may be

interactively defined. The geometric coordinates of all singular points in the network are stored in a data file and all possible branches connecting the nodes are all also defined. The network with redundant branches is consequently determined.

The mathematical problem is then expressed as

$$\text{minimize} \quad \text{Sum}_j \; l_j \; x_j^a, \; j = 1,n$$

subject to

$$\text{Sum}_j \; Q_{ij} = \text{Sum}_k \; Q_{ik} \; \text{(flow maintenance)}$$

$$y_i - y_j = h_{ij} \; \text{(head loss)}$$

$$y_j \geq y_{min} \; \text{(pressure)}$$

$$v_{ij} \geq v_{min} \; \text{(velocity)}$$

Other constraints may expressed if pumps are used or if there are multiple sources or if coefficients of demand simultaneity are considered or if localized head losses are prescribed (A. Templeman, 1993).

4. SOLUTION METHODOLOGIES

The proposed problem is nonlinear in the objective function and in some type of constraints. An immediate approach is consider the use of solution techniques like the feasible direction method, the generalized reduced gradient or the gradient approach. The indirect approach is to use linear approximations of the nonlinear functions and then apply the simplex method. This procedure can be repeated sequentially until a stable solution is found.

Another approach is to simplify the problem and express pipe costs as a function of the flows. These may be calculated using a normal pipe flow analysis method and the resulting problem is a network with costs associated with each branch. The problem is then to find a minimum spanning tree that can be solved, for instance, using a Dijkstra's algorithm (C. Papadimitriou, 1982).

A possible methodology to solve is to assume that there are no velocity constraints and that pipe costs are a linear function of the diameter. In this case the problem is linear and the solution technique is the simplex method which is largely available in commercial software. The only difficulty is that the optimal design variables will have to rounded to the discrete available sizes.

The final results present redundant branches of the network with very small diameters with a final branched pipe network that minimizes the expenditure. The combination of computer aided design packages with adequate problem formulation is an attractive procedure to encourage the use of available optimization commercial software as an effective tool in the cost and design improvement of piping layout.

5. REFERENCES

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