RECOMMENDATIONS

In an international survey[3], conducted in 1985 within Working Commission W-78, Integrated Computer-Aided Design, it is reported that only three systems, of forty-five systems responding, provide tools for handling early design programming requirments. The major areas, supported by the respondents, include drawing production and engineering analysis tools. The responses do not show clearly how interfaces and/or integration are provided in these systems. The results of this test and the evidence of the survey lead to the recommendation that we must carefully and fully investigate the architectural design process to identify the architectural information handling tasks and invent new, innovative, and highly responsive and efficient automated approaches. Everyone must directly benefit from an "integrated" approach for it to be fully and successfully used. The results of the tests show the need for computer-aided drafting to precede computer-aided design, especially in the case of the architect. Further, design tools for the architect will not be the "analysis" tools that the engineer uses. Rather, the tools will provide support for organizing building program information for use in design, organizing layouts and specifications, conducting conceptual-level life-cycle cost studies, and preparing drawings.

The computer software industry, as well as public research institutions, should now recognize, from these test results, the receptiveness of the building design community to utilize these integrated computer-aided design technologies. Research into the topic of computer-aided architectual design, as well as development of new systems, can now be conducted very cost-effectively using lower-cost micro-based equipment. If the value and importance of "integrated" life-cycle costs studies are widely recognized, over the next few years, the industry will accomplish major strides in providing software products tailored to the needs of the architectural process.

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[3] J.Spoonamore, D. Vanier, P. Christiansson, "A Survey of Integrated Computer-Aided Design Systems", presented at CIB W-78 Integrated Computer-Aided Design Symposium, Rotterdam, 16-17 September 1985.

Multistorey building drainage network analysis: a computer aided approach to drainage design

Professor J.A. Swaffield
Heriot-Watt University, Department of Building,
Chambers Street, Edinburgh EH1 1HX, Scotland.

Dr. L.S. Galowin
National Bureau of Standards, Centre for Building Technology,
U.S. Department of Commerce, Gaithersburg, Md 20889, U.S.A.

Key words: Building drainage, computer aided design, unsteady flow

Summary

Flow in a building drainage network may be described as free surface, unsteady pipe flow. Wave action steepens or attenuates inflow profiles depending upon both the system parameters and the shape of the initial profile itself. Appliance discharges are therefore modified by wave action during their passage along the system. Inclusion of wave action in the prediction of system loading provides an enhanced design capability quantifiable in terms of increased loading, the potential use of smaller diameter pipes, and the ability to deal with specific building designs and usage patterns. Current fixture unit design methods cannot do this as they employ steady flow criteria and are based on appliance peak discharge. The equations governing wave action are presented and solved via the computer based finite difference method of characteristics. Computing techniques representing both wave action and the range of initial and boundary conditions to be encountered in a multistorey building drainage network are presented, together with the laboratory results of full scale validation experiments and examples of computer model applications to both U.S. and U.K. design cases. The paper concludes that the application of computer aided engineering to the design of building drainage networks is both feasible and beneficial.

Analyse du reseau d'ecoulement des eaux dans un batiment a plusieurs etages: une approche assistee par ordinateur a la conception de l'ecoulement des eaux.

Professor J.A. Swaffield
Heriot-Watt University, Department of Building,
Chambers Street, Edinburgh EH1 1HX, Scotland.

Dr. L.S. Galowin
National Bureau of Standards, Centre for Building Technology,
U.S. Department of Commerce, Gaithersburg, Md 20889, U.S.A.

Mots-cles: ecoulement des eaux dans les batiments,
ecoulement inconstant dans les tuyaux partiellement remplis,
conception assistee par ordinateur.

Summary

L'ecoulement des eaux dans un systeme pour batiment peut etre decrit comme etant un ecoulement inconstant dont la surface est en contact avec l'air. Les decharges des appareils (menagers par exemple) sont par consequent modifiees par une action des ondes pendant leur passage le long du systeme. L'action des ondes augmente ou attenue les profils d'arrivee d'eau a la fois selon les parametres du systeme et la forme du profil initial lui-meme. L'inclusion de l'action des ondes dans la prediction de chargement du systeme fournit une capacite de conception amelioree, qui peut entre quantifiee en termes d'une augmentation du chargement, l'utilisation de tuyaux de diametre plus petit, et la capacite de traiter des conceptions de batiments specifiques et des modeles d'utilisation. Les methodes actuelles de conception ne peuvent pas accomplir ceci car elles emploient des criteres d'ecoulement constant et sont basees sur les decharges maximum des divers appareils. Les equations qui gouvernent l'action des ondes presentees et resolues par la methode des caracteristiques (a difference finie), basee sur ordinateur. On presente les techniques informatiques representant a la fois l'action des ondes et la gamme des conditions limites qu'on peut recontrer dans un reseau d'ecoulement des eaux dans un batiment a plusieurs etages, ainsi que les resultats d'experiences de validation sur des systemes grandeur nature a NBS et BU et des exemples d'applications de simulation par ordinateur aux cas de conceptions americaine et britannique. La presentation conclut que l'application de l'ingenierie assistee par ordinateur a la conception de reseaux de'ecoulement des eaux dans les batiments est a la fois faisable et profitable.

Introduction

Multistorey building drainage networks are currently designed on the basis of equivalent steady flow loadings derived from the probability of usage based fixture unit method. This technique, due to the work of Hunter(1) at the National Bureau of Standards, Washington, has been the basis of drainage design in both the U.S.A. and U.K. for many years. Summation of the appropriate fixture unit rating for all appliances discharging to a system yields a loading which may be related to pipe slope and diameter as design limits through a set of tables that employ 50% or 75% of full bore steady flow normal depths, calculated via versions of Manning's or Chezy's equation.

However, the flow in a building drainage network is fundamentally unsteady free surface flow, characterised by the wave action modification of an appliance discharge as it propagates along the system. Wave action either steepens or attenuates an inflow profile dependent upon the system parameters, such as pipe diameter, roughness, slope and the flow vs time profile and entry mode of the appliance discharge itself. As wave propagation velocity varies with depth so peaks tend to overtake leading edges and outdistance trailing edges, resulting in a modification to the wave profile. A combination of wave attenuation, i.e. a reduction in the peak discharge flowrate as the discharge passes through the system, together with a superposition of other attenuating (simultaneous or superpositioned at other time intervals) discharges, results in a loading prediction likely to be lower than that arrived at by the fixture unit method. A technique capable of incorporating wave action into network design has a number of advantages, e.g. an increase in the recommended number of appliances discharged to a given pipe diameter or a corresponding decrease in that pipe diameter. Additionally a technique based upon the actual usage pattern and discharge of one or more particular appliances would facilitate studies of water conservation and system flow rates and the associated problems of waste transport or self cleansing, as well as providing a means of studying the surge flow conditions within building collector horizontal drains loaded by the building's vertical stacks.

Basis for the mathematical model

Building drainage networks display unsteady free surface flows defined by the St Venant equations of motion and continuity, i.e. a pair of quasi linear hyperbolic partial differential equations expressing flow velocity and depth in terms of a space-time grid. Following transformation into their total derivative form, these equations may be solved by a first order finite difference method, provided their solutions are limited to two characteristic directions in the x-t plane. This technique, known as the Method of Characteristics, has been available since the mid nineteenth century, but has only become practical in the current application following the advent of fast digital computers.

The St Venant equations of continuity and motion applied to an element of unsteady free surface flow may be expressed as shown in Figure 1, where the unsteady frictional losses are approximated by the local time equivalent steady flow parameters used in either the Colebrook-White or Manning equations.

The resulting pair of 1st order finite difference relationships, known as C^+ and C^- characteristics, link conditions across a time step, dt. The slopes of these characteristics depend upon the free surface flow regime. If $V > c$ then both characteristics are drawn from points that lie upstream, and one time step earlier, implying an inability to transmit information upstream, Figure 1. Known as supercritical flow this is the norm within building drainage networks. Conversely if $V < c$, then the characteristics lie on either side of the node considered so that downstream conditions may be communicated upstream. Such subcritical flow occurs naturally in shallow gradient or very rough pipes, or immediately upstream of restrictions to the flow, such as in the vicinity of pipe junctions, where the subcritical region is forced and terminates upstream in a hydraulic jump. The location of the jump is dependent upon both the flow approaching the restriction and the severity of the restriction, and will vary in response to flow changes in the approach pipe.

Thus it is possible to solve for flow depth and velocity at each node at any time provided adjacent flow conditions at an earlier time step are known. However, for the solution to proceed to model the passage of a discharge through a a system it is also necessary to define the time dependent conditions at the system boundaries, as well as representing such internal boundaries, as junctions.

Figure 2 illustrates the range of boundary conditions for a simple network developed and validated within the current research programme(2,3,4).

Boundary condition representation

No C^+, C^- characteristics can exist at the upstream entry to a supercritical flow region, thus it is necessary to define entry depth and velocity with equations appropriate to the known flow entry conditions to predict the wave action. Discharges from appliances such as baths, sinks and showers have been found to be adequately modelled by the imposition of a normal depth at pipe entry, based upon a known discharge profile, i.e. $Q=f(t)$, and a version of Chezy's equation.

For discharges possessing a high kinetic energy, for example w.c. or vertical stack to collection drain discharges, that entry condition is not valid. The flow entry condition may then be represented by equating the free surface specific energy at pipe entry to some percentage of the stack or w.c. discharge kinetic energy, Figure 2. Again the discharge flow-time profile may be utilised to yield the appropriate inflow rate.

Entry to a downstream pipe from a junction of two or more merging flows is handled in a similar fashion. Due to the flow restriction imposed at the junction, a forced subcritical flow region exists upstream of the junction. To enable the combined flow to re-establish a supercritical flow regime, a critical depth section must exist immediately downstream of the junction. As the combined flow is known, from correctly sequenced finite difference calculations, this depth is given by the critical depth relationship, Figure 2.

A top entry termination from a stack or pipe to a main drain is dealt with directly in supercritical flow as both C^+,C^- characteristics are available. For subcritical terminations the critical depth expression may be solved with the available C^+ characteristic, based on established observations of drawdown at free outfalls.

Similarly downstream terminations at junctions, either top entry or level invert, may be solved by use of the available C^+ characteristics together with an empirical depth vs flowrate relation that represents the presence of a forced subcritical region upstream of the junction; the individual expressions dependent upon the junction design, Figure 2.

Upstream of either type of junction the forced subcritical flow region gives way to supercritical flow via an hydraulic jump. It is necessary to solve for flow depth and velocity on either side of the jump, as well as for the jump velocity. The available upstream C^+C^- characteristics together with the subcritical downstream C^- and the equations of momentum and continuity across the jump yield a set of boundary equations for this situation that allows the solution to proceed, Figure 2. The location of the jump in each pipe so affected is monitored at each time step and the interface between subcritical and supercritical flows adjusted accordingly.

Network analysis

The application of the network analysis program is shown by Figure 3, including each of the boundary conditions mentioned. The response of the system to multiple inflows and the superposition of the discharges is demonstrated. The flow rate and depth at any point in the network may be studied and the design amended due to any low velocity conditions that might indicate likely deposition sites, or where full bore flow regions occur indicating poor junction design or inadequate pipe sizing. The main benefits of such a study lie in its uniqueness to the design of a particular system and the predictive ability to model any usage pattern imposed upon the network.

The predicted discharge from such a network to the vertical stack may be stored as data for subsequent studies of multistorey building systems. Figure 4 illustrates the application of the network program to a 4 storey building, each floor connecting via a single stack to a collection drain. The surge in this collection drain can be predicted utilising the techniques described. Empirical results have indicated that 25 to 40% of the kinetic energy based upon stack terminal flow velocity is available at entry to the collection drain and this observation is utilised to provide the drain inlet upstream boundary. Similarly, a basement level collection network served by several stacks, each collecting from any number of floor networks previously analysed, may be dealt with by the existing computer model. Computer usage time suggests that building up the multistorey, multinetwork analysis in this way is more efficient than dealing with the whole network at one attempt. The peak flow depth indicated at a distance along the collection drain is typical of the predicted surge response of such systems. This indicates that a careful design, in terms of pipe diameters or distances to larger catchment sewers, could substantially increase the rated capacity of a given collection drain.

Model validation and development

The model presented has been validated by laboratory testing on full scale drainage networks in both the U.K. and U.S.A. Figure 5 illustrates a typical validation from the NBS vertical stack facility. Two points are worth noting, namely the agreement between predicted and measured steady flow depths both before and after the surge, and the surge wave agreement in terms of magnitude, shape and time of arrival at the measurement location. Similar validation exists for the other boundary conditions presented(2). However, the method of characteristics is only one of a family of finite difference techniques that are available to solve the St Venant equations for free surface unsteady flows. It was chosen due to its simplicity in the area of boundary condition representation. Other methods may have alternative advantages. However it is important that such models are adequately validated and as such the model presented may have a role as an already validated standard. Further development of the model is required to deal with the possibility of full bore flows, particularly at junctions and in the building collection drains. Junctions have been identified as a major limitation on the capacity of a system and the program could be utilised in the improved design of items based on new standards derived from computed results.

In the long term, the model must be adapted to become the basis for a computer aided design package that will allow the designer to recalculate the specifications for a network on the basis of the predicted flow depths and velocities provided by the model. This development will in no way diminish the need for the designer to fully understand the mechanisms inherent in the operation of the drainage system; indeed, such understanding will become even more important if the full advantages of the model are to be realised.

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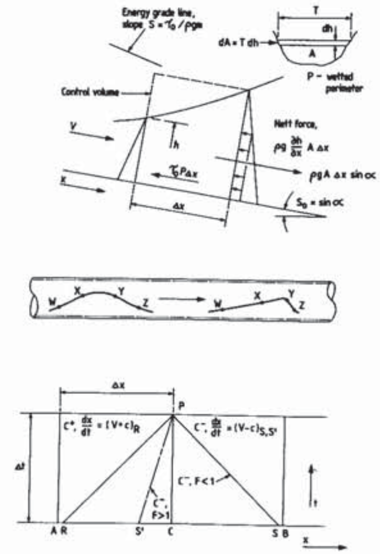

Figure 1 Summary of the development of a Method of Characteristics solution of the wave equations in partially filled pipe flow

The equations of continuity and momentum for an element of flow may be expressed as:

$$g\frac{\partial h}{\partial x} + g(S-S_o) + V\frac{\partial V}{\partial x} + \frac{\partial V}{\partial t} = 0$$

$$VT\frac{\partial h}{\partial x} + T\frac{\partial h}{\partial t} + A\frac{\partial V}{\partial x} = 0$$

reducing to a pair of total differential equations:

$$\frac{dV}{dt} \pm \frac{g}{c}\frac{dh}{dt} + g(S-S_o) = 0$$

limited to two characteristic directions in the x-t plane:

$$\frac{dx}{dt} = V \pm c$$

Wave attenuation occurs in partially filled pipe flows due to the disparity in wave speeds, $c = \sqrt{gA/T}$, i.e. $c_y > c_z$ and $c_x > c_w$, resulting in a steepening wave front and a lengthening tail, as shown.

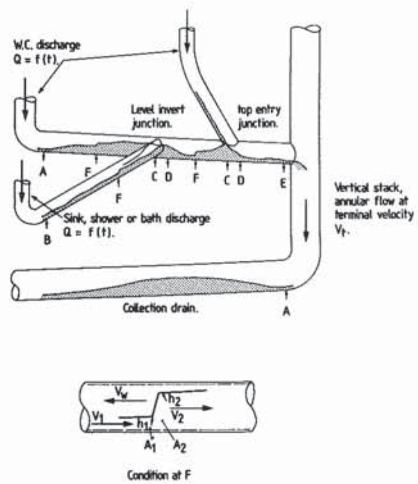

Figure 2 Schematic of simple tree network to illustrate boundary conditions

A. Vertical stack or w.c. discharge to supercritical flow region. Equate entry energy to flow specific energy $KV_t^2/2g = h_A + V_A^2/2g$, where K is % available.

B. Normal depth entry to supercritical flow, based on known $Q = f(t)$ and Chezy equation $Q = 2gA(SoA/P)^{0.5}/f$, friction factor, f, from Colebrook-White equation.

C. Depth at junction given by empirical relationships of the form $h_C = \phi(\Sigma Q, \text{junction shape})$.

D. Entry to supercritical flow region downstream of a junction defined by critical depth at entry, $0 = 1 - \Sigma Q^2 T/gA^3$, i.e. A and T are f (critical depth).

E. Free discharge from supercritical flow region.

F. Hydraulic jump upstream of a junction, solved by use of available C^+, C^- equations together with equations of continuity and motion across the jump, note jump velocity V_W must also be included:-

$$(V_1-V_W)A_1 = (V_2-V_W)A_2$$

$$g(A_1\bar{h}_1 - A_2\bar{h}_2) = A_2(V_2-V_W)^2 - A_1(V_1-V_W)^2$$

where $\bar{h}$ are centroid depths

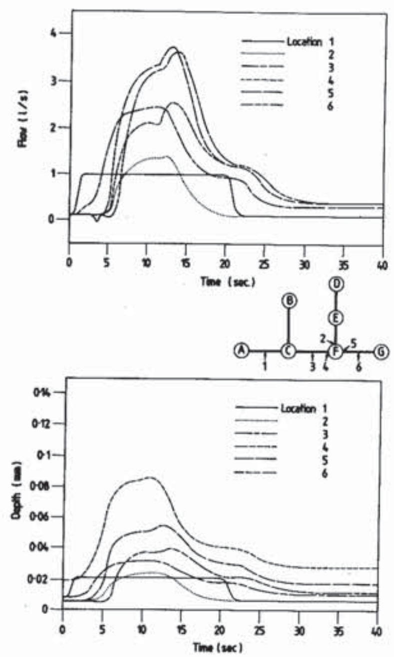

Figure 3 Local flow rate and depth predicted by the model at chosen locations in a pipe network subjected to multiple inflows

All pipes are 2m long, set at 0.02 gradient
Pipes AC, BC, DE are of 75mm diameter
Pipes CF, FG are of 150mm diameter
Pipe EF is of 100mm diameter

Inflow at A simulates a bath with discharge of 1.0 l/s from 0 to 20 s.
Inflows at B and D simulate w.c. discharges of 1.4 l/s from 4 to 9 s, with a 4 s rise and fall time.
Outflow at G is assumed to be to a vertical stack.
Note that all times are measured from a common time zero.

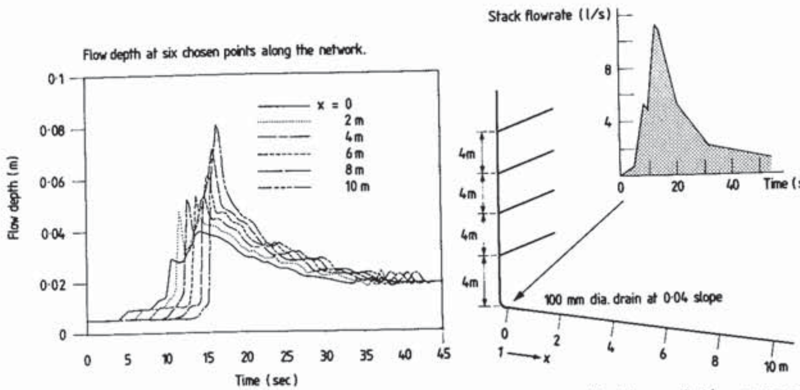

Figure 4 Application of the computer model to the prediction of the surge capacity of a building collection drain serving a 4 storey vertical stack.

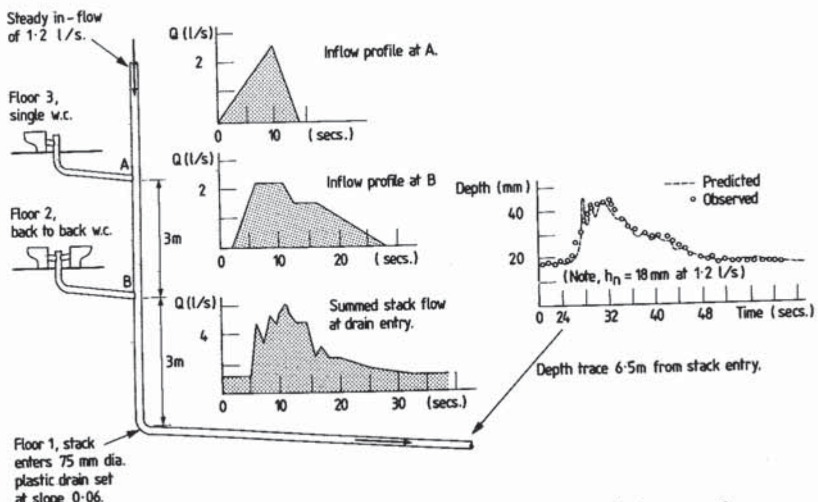

Figure 5 Validation of the computer model at the National Bureau of Standards, Centre for Building Technology, plumbing tower facility.

Computer Aided Design of Time Depending Structure-Soil Interaction

Ludvik Trauner

University of Maribor
Faculty of Technical Sciences
62000 Maribor, Yugoslavia

KEYWORDS

Geomechanics, Structure-Soil Interaction, Non-linear, Time Dependant, Deformation Analysis.

ABSTRACT

The paper presents graphical interpretation of non-linear time dependant interaction between elastic structure and high flexible non-homogeneous (layered) soil. The use of program has been shown on space reinforced concrete frame structure on a layered halfspace.
Time dependant displacements were evaluated successively by computer as to load path and the consolidation process in soil of viscous unequal thickness clay layers on a rock basis. The program uses deterministic analysis on a theoretical Kelvin´s rheological model. An incremental iterative method is used: skeleton structure is presented by linear finite elements but the soil is described using analytical function defining non-linear and time dependant relations. Rheological soil characteristics were determined with slow, drained triaxial tests and monotonouosly increasing (decreasing) load.
A graphic simulation of structural displacements during the construction and after it has been built up enables better, faster, more economical design and higher safety in everyday engineering practice.