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Louvred Intake for Arresting Silt and Debris

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by

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LOUVRED INTAKE FOR ARRESTING SILT AND DEBRIS

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SYNOPSIS

The importance of preventing intake blockage, in designing reservoir outlets and diversion tunnels, is stressed. A general philosophy for the design of submerged intakes is presented, together with some basic criteria based on experience. A louvred type of intake for automatically arresting floating debris and preventing sediments entering outlet forebays, is described. Hydraulic model tests, using sediments ranging from coarse sand to clay, generally confirmed its efficacy, its performance improving with grain size, internal friction angle, and reduced louvre dimensions. Stability analyses for cohesionless and cohesive media lead to relationships between the maximum sediment depth retained by louvres of different proportions and profiles, and the sediment slope and depth inside the louvre. The derived graphs are reviewed in the light of the model test results. The effective operation of a louvred tunnel intake on a small mountain stream, is described. The general conclusion is that the louvred intake can retain granular materials to substantial heights, and cohesive finer media to moderate heights; even clays are effectively supported, provided the ratio of louvre "throat" to effective grain size exceeds some definite "choking" limit.

Cet article met l'accent sur l'importance qu'il y a à prévenir toute obstruction des prises d'eau lors de l'étude des orifices d'écoulement et des tunnels de diversion des barrages. Il présente des principes généraux à appliquer au départ lors de l'étude des prises d'eau immergées ainsi que certains critéres de base découlant de l'expérience.
L'article décrit une prise d'eau équippée de chicanes, lesquelles arrêtent automatiquement tout objet flottant et empêchent les dépôts sédimentaires de pénétrer à l'intérieur des conduites de sortie des bassins d'accès aux prises. Des essais hydrauliques sur modèle, au cours desquels on a utilisé des sédiments allant du sable à gros grains jusqu'à l'argile ont fait la preuve de l'efficacité de ces chicanes; cette efficacité augmentant avec la grosseur du grain, avec l'angle interne de friction et avec la réduction des dimensions des chicanes.
Les analyses de stabilité pour des milieux cohésifs ou non amènent à établir des rapports entre d'une part l'épaisseur maximum de sédiment retenu par les chicanes selon leurs proportions et leurs profils différents et d'autre part la pente de la couche de sédiment et son épaisseur du côté interne des chicanes. Les courbes graphiques obtenues sont modifiées compte tenu des résultats des essais sur modèle. L'article en question décrit une opération réelle effectuée par une prise en chicanes dans un petit cours d'eau de montagne.
En conclusion générale, la prise d'eau avec chicanes parvient à retenir les matériaux granuleux à des épaisseurs substantielles et les mélanges cohésifs plus fins à des épaisseurs modérées; les argiles mêmes sont efficacement retenus à condition que le rapport entre l'écartement des chicanes et la grosseur réelle des grains dépasse une limite définie d'étranglement.

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INTAKE OBSTRUCTION

Introduction

The intakes of reservoir outlets or diversion tunnels on streams with high concentrations of debris, suspended matter and bed-load sediments, are vulnerable to partial or complete blockage. Extensive log booms, large trashracks, and movable crests or bypass outlets of very large capacity, are costly and not always fully effective.

Experience of Blockages

The 1943-44 drought in Victoria severely depleted all reservoirs, and intake blockages occurred at three storages built early this century, necessitating expensive clearing and outlet remodelling to maintain supplies. This experience showed that submerged intakes should be not only set sufficiently high to provide a substantial silt storage and provided with adequate trash-racks, but also: a) positioned away from abutments to avoid blockage by wave erosion of slopes or secondary scour of the deltaic deposits of adjoining streams, aided by rapid pool-level variations, and b) provided with facilities for clearing blockages, and maintaining and servicing the shut-off devices.

Philosophy of Intake Design

Sedimentation is a natural process and cannot be eliminated altogether; it can only be suppressed or controlled. But the careful location and design of intakes and outlets can avoid protracted interruptions to water deliveries, with consequent hardships and large revenue losses. Moreover, the clearing and reinstatement of intakes and outlets are hazardous and expensive operations, and often merely postpone the inevitable major remodelling. Therefore, intake and outlet design should aim at: a) preventing complete blockages; b) providing access for cleaning, repairs and maintenance; and c) facilitating future remodelling. The extra cost involved is justified by an improved security of supplies, and offset by a reduced capitalized cost of annual charges and future remodelling.

The abovementioned design criteria should be dominant, and yet they are often ignored: Intake failures rarely appear in the technical literature. As most of today's headworks are very young on the sedimentation time scale, relatively little experience of major intake blockages has accrued. Therefore, many intakes will have a much shorter effective service life than the outlet itself, the headwork structure, or the reservoir. An unrealistic design philosophy merely bequeathes the inevitable obstruction problems to another generation.

LOUVRED INTAKE

Fundamental Concept

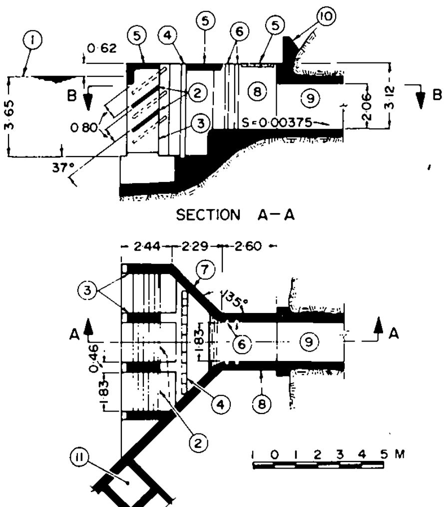
An ideal intake would automatically prevent the movement of sediments and debris into the forebays of outlet conduits, and yet permit the free passage of water with reasonable head loss. It should also meet the other design criteria mentioned above.

A study of the characteristic motions of water, floating debris, and suspended and bed-load sediments, led the writer to the development of a louvred intake structure[1] comprising Z-shaped beams with sloping webs, each upstream flange projecting below the downstream flange of the next lower beam (Fig. 1). The basic principle was that the overlap h would not only arrest floating debris but also develop sufficient passive sediment pressure inside any louvre to resist the active pressure due to the design sediment depth H outside, the overlap ratio H/h depending on the sediment properties.

Hydraulic Model Tests

A perspex-faced model 1.2 m high with louvre throat sizes t of 30 or 300 mm, was built to test coarse sand, sandy silt, a 1:1 clay-silt mix, and clay. The granular materials were ladled directly into the water-filled model, but the clay and the clay-silt mix were first saturated and stirred in a concrete mixer. A 100-mm grid of fine strings was attached to the perspex window. Also, "marker" layers of fine white gravel were placed between successive horizontal

1. MICHELS, V.S., and ILOTT, L.P. - "Reservoir Outlets and Control Works." Trans. I.E. Aust., Vol.27, No.7-8, July-Aug., 1955, pp.173-87.



9 Goodmans Creek Diversion Pool: Large Area of Floating Debris after Flood.

Bassin de diversion dans le "Goodmans Creek": àpres inondations, des débris flottant sur une vaste éntendue.

8 Main Features of Louvred Intake, Goodmans Creek Diversion Tunnel.

1) Full pool level.
2) Removable louvres of prestressed concrete slabs.
3) End walls and piers.
4) Trash rack of precast concrete bars.
5) Access platforms.
6) Slots for drop-bars or gate.
7) Transition.
8) Flume Section.
9) Tunnel.
10) Protective Wall.
11) Pit for Outlet and Water-Level Recorder.

Caractéristiques principales d'une prise à chicanes. (Tunnel de diversion dans "Goodmans Creek".)

1) Niveau maximum du bassin.
2) Chicanes amovibles en béton précontraint.
3) Murs et pilliers de soutènement.
4) Grille en barres de béton pré-coulé.
5) Plateformes d'accès.
6) Glissières pour planches - vannes.
7) Transition.
8) Bief de décharge.
9) Tunnel.
10) Mur de protection.
11) Fosse de logement de la valve de décharge et de l'appareil de lecture de niveau d'eau.

fillings upstream, and a hinged trapdoor released inside one louvre to simulate rapid sediment motion into the forebay (Fig. 7). The test results are presented in the table below, and typical sediment profiles and movement patterns are shown in Figs. 6 and 7.

Test No.	Throat t, mm	Material under test	Silt depth, mm H	h	Profile of silt inside louvre towards outlet	Notes
1	300	Coarse sand	610	0	Down-ward, concave up.	No sand flow into louvre initially, and throughout build-up of sand depth upstream; rapid draw-down failed to dislodge sand.
2	300	Sandy silt	710 710	0 8	Down-ward. Horiz-ontal.	No silt flow into louvre. After silt inside louvre was removed by shovel, some silt ran into louvre.
3	300	Silt-clay mix (1:1)	685	150	Horiz-ontal.	Continued rodding inside louvre failed to disturb mix. Mix gained strength as H was increased. Rapid draw-down failed to dislodge mix.
4	300	Clay	610	290	Down-ward, convex up.	Clay ran over downstream lip and through outlet. Upon draining water, clay levels drew closer.
5	300	Clay	815	290	Down-ward, convex up.	Clay on point of movement, pressed down on upstream side, water drawn off. Clay moved in and spilled over, motion recorded by white gravel.
6	300	Clay	815 815	0 290	- Down-ward, Convex up.	Closed off. Trapdoor then released. Clay slipped into louvre but did not spill over downstream sill. (Perspex covered by 100-mm grid.)
7	30	Coarse sand (also sandy silt)	760	0	As for Test No. 1.	No flow of sand into louvres observed as sand level raised upstream. Rodding upstream showed sand was very dense inside louvres, but none dislodged.
8	30	Clay	760	32	As for Test No. 4.	Clay flowed in initially but stopped immediately a louvre inlet was sealed off by clay upstream.

The tests indicated that: a) the louvred intake is very effective in completely or moderately arresting inward sediment movement; b) highly moisture-laden clay is not fully arrested by the larger louvres (t = 300 mm), but its overflow is harmless, as it can pass through the forebay and the conduit; c) the retention head H increased generally with the grain size or the internal friction angle of the saturated material, or with decreasing throat t; d) for each grain size, and depending on sediment strength, there is evidently some maximum value of t for which an unlimited H can be supported; e) the initially loose clay and silty clay are rapidly consolidated and strengthened under static surcharge and induced dynamic conditions; f) the boundary undergoing maximum shear strain is a near-vertical plane close to the upstream flanges; g) no appreciable movement occurs above the sloping web.

Theoretical Studies

A relationship was sought between the maximum depth that a sediment of known characteristics can be retained by louvred intakes of different dimensions and profiles, and the sediment slope and depth inside the louvre (Fig. 2).

Initial Considerations. For cohesionless materials, assuming Profile III, Rankine's Theory yields the obvious solution:

$$H/h = \left\{(1 + \sin\phi)/(1 - \sin\phi)\right\}^2 = N_\phi^2 \quad , \qquad (1)$$

where ϕ is the angle of internal friction (for simplicity, assumed equal to the angle of repose) and N_ϕ is the flow value. For the Revised-Wedge Theory[2]

$$H/h = N_{rw}^2, \qquad (2)$$

where N_{rw} is the ratio of the vertical pressure due to the sediment upstream, to its maximum horizontal component on a vertical plane, measured at O. The curves of Eqs. (1) and (2), see Fig. 4, diverge rapidly because the latter theory pertains to a freely rotating retaining wall, and the resulting maximum horizontal components are less than the wholly horizontal, Rankine pressures. Here, the soil mass probably moves into the stationary inlets, following consolidation upstream. Also, repacking of a loose sediment normally increases ϕ, and local deformations may cause arching. Therefore, for cohesionless media, H/h probably corresponds initially to the Rankine value, and subsequently increases — possibly up to the Revised-Wedge value (for the same or a greater ϕ).

Sediment Profiles inside Louvre. The observed profiles indicated that the detailed theoretical studies could be confined to: Profile I for primarily granular materials (cohesionless or weakly cohesive); and profile III for materials which, when submerged, have a low or significant cohesion and a fairly small ϕ value; profile II is intermediate.

Study No. 1. Based on typical sediment displacements (Fig. 7), a simple J-shaped sliding surface (No. 1, Fig. 2.a) was analysed. This resembles Terzaghi's "base failure" profile for a vertical bank, intersecting the sediment horizon at right angles (the material can move laterally into the stationary louvres). Alternatively, the lateral movement creates the conditions associated with a yielding lateral support pivoting about its upper edge, causing arching and the relief of the horizontal pressures over its lower back face. For the incipient-slide condition, the solutions for the various profiles are:

$$M_I = \frac{2}{3}\left\{\frac{2 + \sec\phi - \tan\phi + 3k(\pi - \phi)\cot\phi}{(1 - 2k)\,(\cot\phi - \pi/2)}\right\};$$

$$M_{II} = \left\{\frac{8/3 + 2\pi k.\cot\phi}{(1 - 2k)\cot\phi - \pi/2}\right\}; \qquad (3)$$

$$M_{III} = \left\{\frac{8/3 + 2(\pi k + m)\cot\phi}{(1 - 2k)\cot\phi - \pi/2}\right\} - m\,;$$

where $M = H/t$, $m = h/t$, and $k = c/\gamma' t$, c being the cohesion and γ' the unit (submerged) weight of the sediment. A set of these families of curves is shown in Fig. 3 (m = 0, II) and 4 (m = 1, III).

Obviously for each k value all the profiles have an asymptotic ($M \rightarrow \infty$) value of ϕ when $\tan\phi = 2(1 - k)/\pi$. Also, dry or waterlogged, cohesionless (k = 0) sediments with values of $\phi \geqslant$ artan $(2/\pi)$ or $32\frac{1}{2}^o$, would be retained to an unlimited H upstream. In this case, $28^o < \phi < 34^o$ say, therefore $M_I \geqslant 6$ and $M_{II} \geqslant 9$, whereas Tests Nos. 1, 2 and 7 suggest $M \geqslant 25$.

For media with significant cohesion and low ϕ values, profile III applies, and Eq. (3) can be rewritten by putting $k' = k/M = c/\gamma' H$ (a constant for any given design):

$$(2k'\cot\phi)M_{III}^2 - \left\{\cot\phi - \pi/2 - 2k'\cot\phi(\pi + m)\right\}M_{III} + \left\{8/3 + m(\pi/2 + \cot\phi)\right\} = 0, \qquad (4)$$

to give direct or graphical solutions for M_{III}, for any values of γ', c, ϕ, and m(or t); also $H/h = M_{III}/m$.

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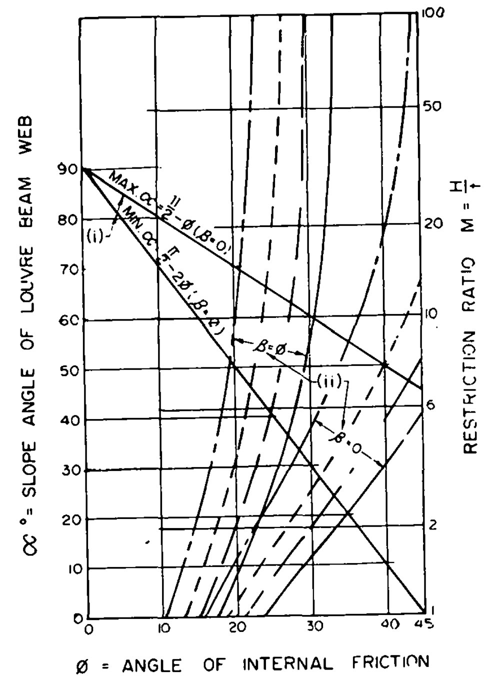
2. JENKIN, C.F., and BEVAN, R.C. Earth Pressure Tables. Dept. of Scient. & Industr. Res., Building Research Spec. Report No. 24, 1934, 101 p.



5 Stability of Cohesionless Sediment (profile I) between Louvres, for $\beta = 0$, and $\beta = \phi$:

i) Maximum and minimum values of α, varying with ϕ, to give infinite M.

ii) Families of curves showing variation of M with ϕ, for different values of α.

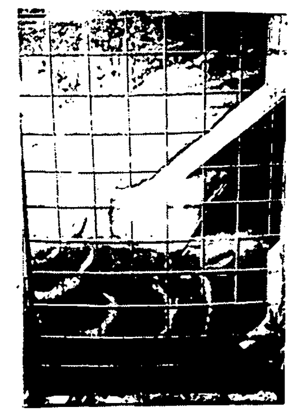
Stabilité des dépôts sédimentaires non cohésifs (Profil I) entre les chicanes, $\beta = 0$ et $\beta = \phi$:

i) Valeurs minimales et maximales d' α variables selon ϕ pour obtenir M infini.

ii) Groupes de courbes montrant les variations de M par rapport à ϕ pour différentes valeurs d' α.

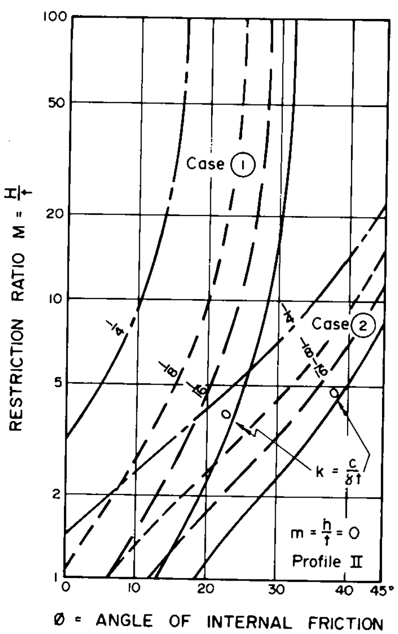
6 Hydraulic Model Tests: Profile of Sandy Silt (Test No. 2) after gradual filling upstream.

Essais hydrauliques sur modele: Profil de dépôt (vase) sablonneux (essai No. 2) après apport graduel en amont.



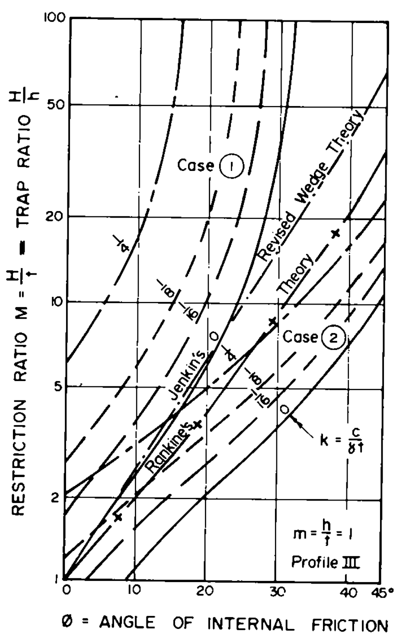
7 Hydraulic Model Tests: Simulated Rapid Flow of Clay into Louvre (Test No. 6) upon releasing Inlet Trapdoor.

Essais hydrauliques sur modele: Apport rapide simulé d'argile dans une prise à chicanes (essai No. 6) après ouverture de la trappe d'admission.



3 **Variation of M with ϕ, for profile II (m = 0) and different k values.**

Variation des courbes M par rapport à ϕ dans Profil II (m = 0) pour des valeurs différentes de k.



4 **Variation of M with ϕ, for profile III (m = 1) and different k values.**

Variation des courbes M par rapport à ϕ dans profil III (m = 1) pour des valeurs différentes de k.

Also, provided the assumed sliding surface still applies to media with $\phi \to 0$ when submerged, the minimum restriction ratios will drop to:

$$\left.\begin{array}{l} M_I \text{ and } M_{II} \;\to\; \{2k/(1-k)\}\pi; \\ M_{III} \;\to\; \{2k/(1-k)\}\pi\,.(1+\frac{m}{\pi k}) - m. \end{array}\right\} \phi \to 0 \qquad (5)$$

Obviously, M depends primarily on k (also on m, for profile III); as $k \to \frac{1}{2}$, $M \to \infty$, and the curves move rapidly towards the $\phi = 0$ abscissa; M is small for small k values, but rises rapidly as m is increased (even if k is small). Therefore, depth H for clays could be large if h is made sufficiently high and/or t is greatly reduced. These deductions also generally agree with the model test results.

Study No. 2. In this case, the main sliding plane was assumed inclined at $\psi = \pi/4 + \phi/2$, the angle of maximum shear stress in a cohesionless medium in the active Rankine state of plastic equilibrium, retained by a wall which yields either horizontally or by pivoting about its lower edge. This alternative probably also does not fully represent the actual conditions, and appears less realistic, but was investigated as a possible outer failure profile. The solution for profile II is

$$\begin{aligned}&\{3\cos\psi(2\cot\psi\tan\phi-1)\}M^2 + 3\{\cos^2\psi(2\cot\psi\tan\phi-1) + \\ &+ (\psi\tan\phi - 1) + 4k.\mathrm{cosec}\,\psi\}M + \\ &+ \{3\cot\psi\cos^3\psi + 2\sin\psi\,(1+\cos\psi)(2+\cos\psi) + 4\}\tan\phi + \\ &+ 6k(\cot\psi + \pi/2 + \psi) - \cos^3\psi = 0 \end{aligned} \qquad (6)$$

For profile III, the factor $3\{1 + (\pi/2)\tan\phi + 2k\}$ m is added to the constant term. Typical sets of these families of curves are shown in Figs. 3 (m = 0, II) and 4 (m = 1, III).

In this case, M grows almost linearly with k and ϕ, but increases less rapidly than in Study No. 1, and is much lower (M = 2 to 5 maximum) than observed in model tests on sand and sandy silt (M = 25 minimum). Moreover, for cohesionless media (k = 0), the asymptotic ($M \to \infty$) values of ϕ greatly exceed $\pi/4$ — the probable practical limit, which is very unlikely.

Study No. 3. For a cohesionless material, the stability of the triangular wedge resting (profile I) in a louvre (Fig. 2.b) was prompted by the consistency with which this result was obtained in the model tests, typified by Fig. 6. Two factors improve the stability of the triangular wedge and, hence, the sediment-arresting properties of the louvred intake: a) As such a sediment is progressively deposited, consolidation gradually develops shearing stresses along AOB, the initial strain being absorbed by the repacking of its grains, thereafter generating high friction angles under relatively little additional strain. Therefore, the resultant pressure P must dip downward; in the limit, $\beta \to \phi$; b) the upward slope α of the louvre web, largely determines the friction angle δ of reaction R, which has an upper limit of ϕ .

Assuming an active Rankine state, this stability analysis leads to

$$\begin{aligned} W &= (\gamma' t^2/2).\sec^2\alpha/(\tan\alpha + \tan\phi); \\ P &= (\gamma' t^2/2).(2M_I + \sec\alpha).\sec\alpha\tan\phi/N_\phi . \end{aligned} \qquad (7)$$

Because, in the limit, $\delta = \phi$, we have:

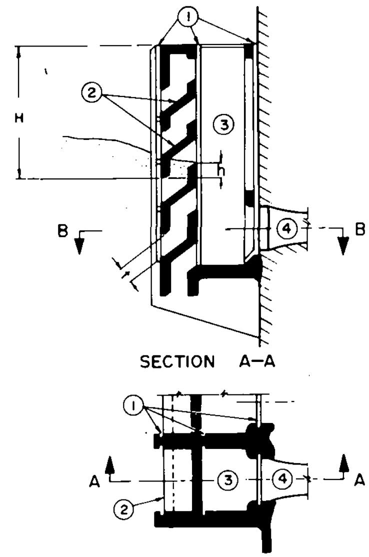
$$\begin{aligned} \text{a)}\quad M_I &= \tfrac{1}{2}\sec\alpha\left[\{N_\phi/(1-\tan\alpha\tan\phi)\} - 1\right] \text{ for } \beta = 0; \\ M_1 &= \tfrac{1}{2}\sec\alpha\left[\{N_\phi/(1-2\tan\alpha\tan\phi - \tan^2\phi)\} - 1\right] \text{ for } \beta = \phi . \end{aligned} \qquad (8)$$

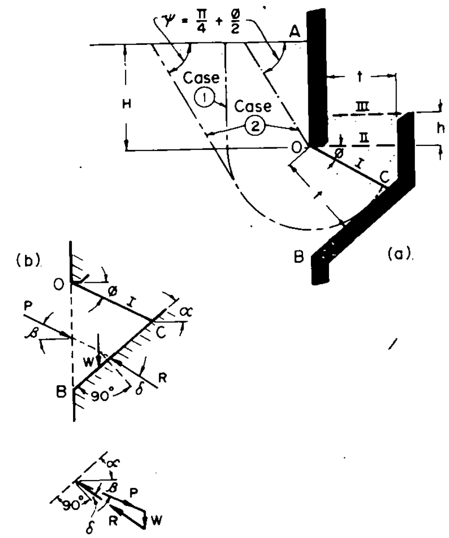
Sets of these families of curves are shown in Fig. 5, together with the asymptotic ($M \to \infty$) values of α for any ϕ value, namely $(\pi/2) - \phi$ for (a) and $(\pi/2) - 2\phi$ for (b). Because the asymptotic ϕ value for any given α is doubled when β is changed from ϕ to 0, the curves for low α values intersect the $\phi = \pi/4$ abscissa at very much lower M values, thereafter passing into an unreal ϕ range. Also, Eq. (8.a) does not agree with the test results, excepting during the initial sediment-deposition stage, and it appears likely that, in fact, $\beta \rightarrow \phi$, i.e. Eq. (8.b) is more realistic. Moreover, horizontal arching between the upstream flanges must substantially reduce P (and hence δ). Lateral displacements into the louvres probably cause horizontal dilatation and vertical shortening, thus promoting partial transfer of the superimposed sediment weight onto the front flanges and ledges, and as frictional forces acting along near-vertical planes located upstream.

Prototype Intake. The first stage of the Merrimu Reservoir Project included a concrete-lined tunnel of 11.3 m^3/s capacity for diverting Goodmans Creek, a narrow mountain stream with steep, timbered banks and a substantial grade (nearly 1%), filled with boulders, gravel, sand and debris. It appeared likely that floods would rapidly fill the relatively shallow (6 m) diversion pool, up to tunnel invert level. Several alternatives for the diversion weir were considered: Movable-crest designs employing vertical-lift (undershot) gates or inflatable flexible-tube (overshot) weir elements were rejected, mainly on cost grounds, and a fixed-crest earth-and-rockfill overflow weir with a gently sloping, rock-armoured downstream face, was finally adopted. Therefore, the tunnel intake had to be specially protected against blockage. The adopted design (Fig. 8) comprised a triple-bay parallel-sided upstream section with sloping louvres for arresting: 1) large floating debris (a small clearance between successive louvres was provided to permit the finer debris to dribble over, as the pool rises), and 2) accumulated bed-load sediments (these can be excavated when necessary, during a later, dry season). Several sharp floods, particularly the first, brought down large quantities of logs, branches and leaves, leaving a large area of flotsam on the dropping pool (Fig. 9). The louvres proved very effective in preventing the massive ingress of both large and small debris, and did not restrict flow down the tunnel. The efficacy of its silt-arresting function, has yet to be proved.

CONCLUSIONS

1. The pilot model tests, the limited theoretical studies, and the initial prototype performance, generally confirmed the basic concept and the sediment- and debris-arresting properties of the louvred intake.
2. The louvres will definitely arrest cohesionless or cohesive granular media to substantial retention heights, and may also satisfactorily retain cohesive materials with medium ϕ values, up to moderate heights.
3. For clays and materials with low ϕ values, the model and analytical results cannot be extrapolated indiscriminately to full-scale structures of larger throat dimensions. However, a limited spillage of such media through the louvres is tolerable, since they are unlikely to block the conduit inlet.
4. The basic assumptions, derived graphs, typical sediment characteristics, geometric boundary conditions, and the correlation between theoretical analyses and model tests, all indicate that the slip profile of Study No. 1 is more realistic than that of Study No. 2. Also, the stability theory of Study No. 3 appears quite realistic for cohesionless media, and may also apply to cohesive materials with substantial ϕ values.
5. The pilot model tests suggest that below some definite ("choking") ratio of throat t to effective grain size, estimated at 10^4 to 10^5, even very fine materials can, upon consolidation, be supported to an unlimited retention head H.
6. The derived graphs must be used with caution, pending detailed hydraulic tests and experience with full-scale structures. Naturally, the designer should also consider the structural and hydraulic factors governing the multi-purpose duty of the louvred intake, including its strength and its waterway efficiency.





1 **Louvred Intake Structure.**

1) Slots for gates to control flow or regulate scour.
2) Z-shaped louvre.
3) Forebay.
4) Outlet.

Prise d'eau équippée de chicanes.

1) Ouvertures de vannes destinées à contrôler l'écoulement d'eau ou à régulariser la quantité de dépôts entraînée.
2) Chicanes en Z.
3) Bassin d'accès aux prises.
4) Goulot de décharge.

2 **Diagram for Stability Studies.**

a) Sediment profiles and assumed sliding surfaces.
b) Stability of sediment wedge inside louvres.

Diagramme en vue d'étudier la stabilité.

a) Profils des dépôts sédimentaires et angle de pente théorique.
b) Stabilité du dépôt sédimentaire coincé du côté interne des chicanes.