Hydraulic Characteristics of Retards

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ABSTRACT: *Retards have been widely used for river bank protection and stream alignment in Victoria. To date little analytical information has been available for use in the design of retards. This research outlines how retards affect flow. The effect of rail spacing, retard height, and the longitudinal spacing of the retards was investigated. These results provide designers with some analytical inputs for the design process and should lead to a better understanding of how retards work to prevent erosion and encourage deposition.*

1 INTRODUCTION

Retards are low fences that extend from the river bank into the stream and are typically constructed of log rails attached to steel or timber piles. The intention of constructing retards is to stop erosion of the toe of the bank and to encourage the deposition of sediment, which in turn will encourage the establishment of vegetation. Generally the design will be such that the deposition of sediment will result in the formation of a new bank line. Thus retards are effectively used for flow alignment works.

To date the design of retards in Victoria has largely been based on experience and general guidelines published in 1991 (Drummond and Tilleard, 1991). This research aimed to extend these guidelines and to develop some analytical relationships for use in design of retards. The areas covered include:

- how retards work;
- retard porosity (rail spacing);
- retard height and the effect of submergence;
- zone of influence;
- angle of the retard to the flow;
- multiple retards;
- sediment stability.

The laboratory research was carried out at the University of Melbourne using scale models. The flume used was 36 m long, 0.925 m wide, and set at a slope of 1:1500. Velocities were measured at regular depths and intervals across the flume using a 10 mm diameter propeller style current meter. Some sediment studies were carried out to provide quantitative answers to some of the hydraulic theories. Dye traces were also injected into the flow to allow visual studies of how the flow was affected by the retards. The model retards used were 300mm long and 150mm high, constructed from 6mm steel rod. The spacing between the rods was varied to give different porosities. Tests were carried out for Froude numbers ranging from 0.5 to 0.1 and flow depths of twice, one and half, and one times the height of the retard.

2 HOW RETARDS WORK

Originally it was thought that retards worked by providing a backwater effect upstream, reducing velocities and allowing sediment to deposit. While retards do cause a minor afflux and associated backwater affect, this was found to only have a minor contribution to the success of retards in stopping bank erosion and providing the suitable hydraulic conditions for the deposition of sediment. Primarily retards protect a bank and cause sediment deposition by providing a resistance to flow in a section of the channel. This slows the flow in the immediate vicinity behind the retard and causes the flow to concentrate in the unaffected (no retards present) section of the channel. This velocity reduction is mainly downstream of the retard (Figure 1).

Given that retards have their greatest influence downstream, it is possible to site a series of retards such that the downstream retard is within the area of influence of the upstream retard(s). This allows a cumulative velocity reduction to be developed.

3 RETARD POROSITY

The effect of the retard porosity on the downstream velocity was examined. Retard porosity, or percentage open, is defined as the percentage of the frontal area of the retard that is open (see Eqn. 1).

The results from this section of the research indicated:

- that the relative downstream velocity (see Eqn. 2), was independent of the upstream velocity and varied with depth of flow. Hence, at a given flow depth, the one set of results is applicable to all flow velocities. This finding agrees with hydraulic theory (Dyer et. al, 1995) and allows the results determined from scaled hydraulic modelling to be directly applied to the field situation; and
- that as the porosity decreased, so did the relative velocity.

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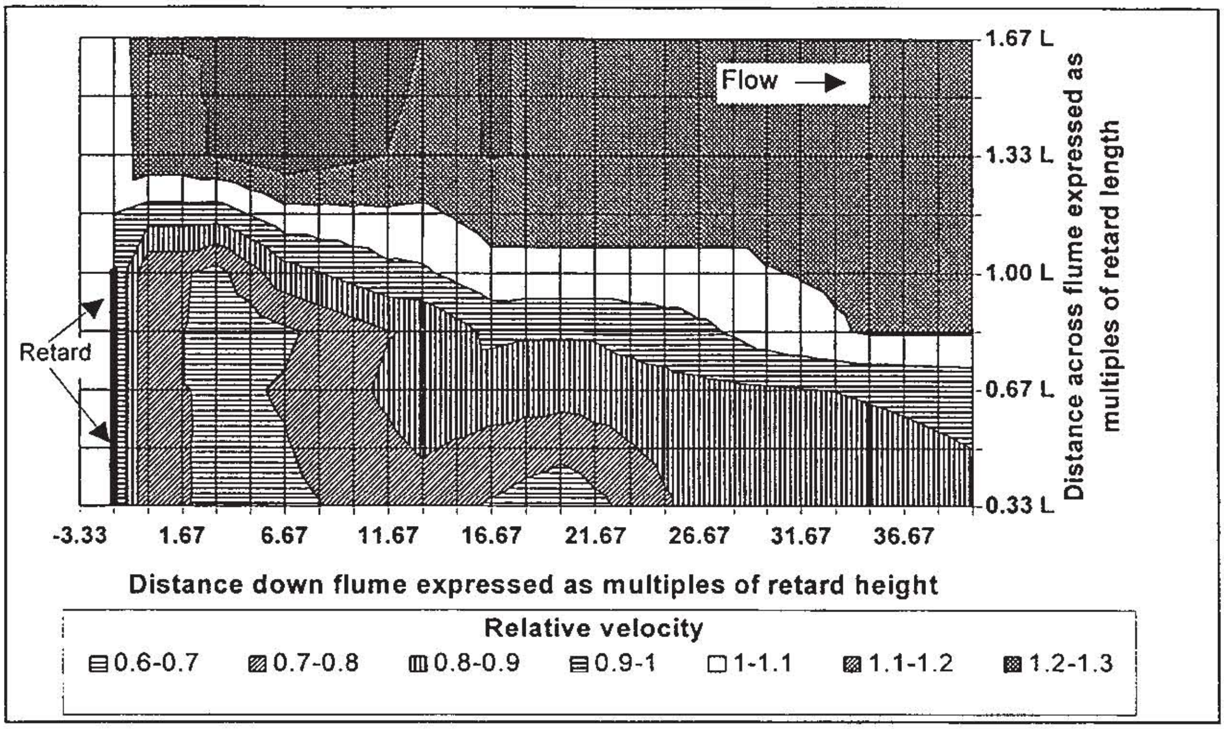

Figure 1 Plan view of relative velocities behind a retard of 50% porosity. Note that these results are for a straight flume and are unlikely to be applicable to flow around a bend. Also note that the plot does not go to the edge of the flume (as this area it is influenced by edge effects and is not typical of general flow conditions).

$$\text{Percentage open} = \left(1 - \frac{\text{frontal area of bars}}{\text{frontal area of retard}}\right) * 100 \quad (1)$$

$$\text{Relative Velocity } \% = \frac{\text{velocity behind retard}}{\text{original velocity}} * 100 \quad (2)$$

The results for the effect of porosity on the relative velocity are given in Figure 2. These results allow the designer to determine the effect of different retard construction on the downstream velocity and hence determine the economic benefit of each design. For example the cost of closer rail spacing (ie. a reduction in the porosity) may be outweighed by the associated decrease in the relative velocity. Thus while the overall cost of the project increases, the risk of the retards failing can be reduced.

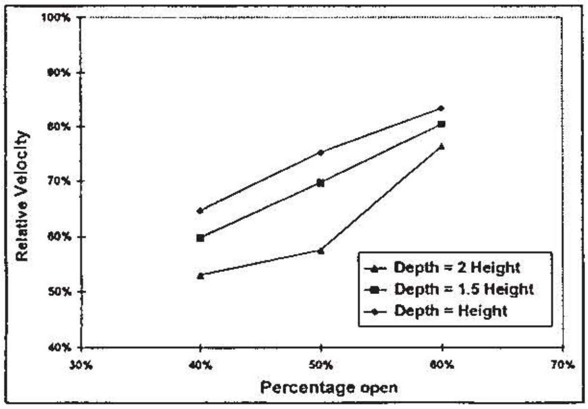

Figure 2 Average results indicating the effect of porosity on relative velocity at a point 1.5 times the height of the retard downstream of the retard. The different curves are for different flow depths which have been expressed as multiples of the retard height.

4 SUBMERGENCE

Retards are constructed in river beds and are exposed to a wide range of flow depths. Figure 2 shows that the relative velocities varied with the depth of the flow. As the depth of flow increased the relative velocity decreased because it was easier for the flow to divert over the top of the retard.. The implication for design is that as the flood magnitude increases, the relative velocity decreases. The designer should be able to relate the velocities associated with flood stage to the relative velocities associated with that depth of flow over the retard and hence determine how the absolute velocity behind the retard varies with flood stage and magnitude.

It must be appreciated that when the retard is submerged, the velocity profile of the flow is severely affected by the retard. Figure 3 shows the velocity profiles recorded in the laboratory for flow over a single retard. The two profiles recorded downstream (d/s) of the retard have much lower velocities in the area affected by the retard, ie. the area below the top of the retard. The velocity of the flow that passes over the retard is higher than the velocity that would have existed had the retard not been in place (the control velocity). The designer needs to consider how this high velocity will affect

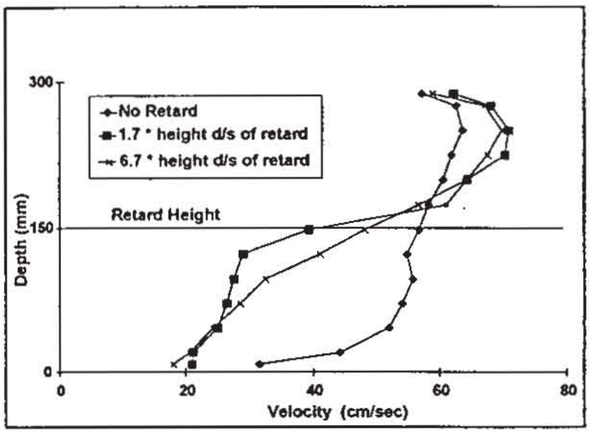

Figure 3 Velocity profiles recorded in the laboratory. Note how the velocity profiles downstream of a retard have higher velocities for the flow above the retard than occur for no retard.

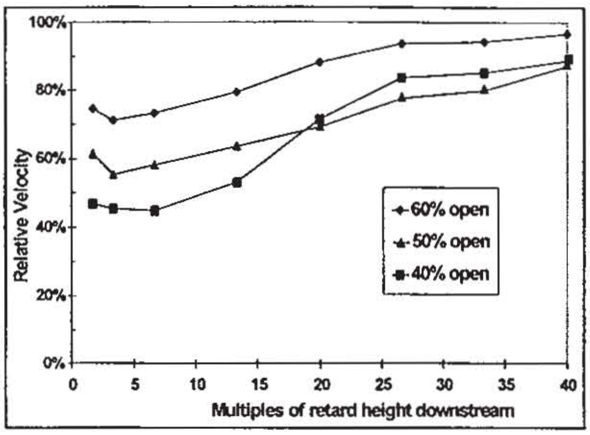

Figure 4 Relative velocity versus the distance downstream of the retard, expressed as multiples of the retard height.

the bank above the retard and include this consideration in determining the height of the retard.

5 RETARD HEIGHT AND DOWNSTREAM INFLUENCE

As discussed above retards reduce the velocity of the flow behind the retard but do not reduce the velocity of the flow over the retard. The reduction in the flow velocity behind the retard can be observed for a considerable distance downstream. Figure 4 shows the relative velocity for three different values of retard porosity and how the relative velocity increases downstream of the retard. The designer can use these results to determine how far downstream the retard provides effective protection (ie. reduces the velocity sufficiently) for the site under consideration. This can then be used in determining the location of the next retard. The designer will need to recognise that the downstream effect is a function of the height of the retard. Thus the design height of a retard can be adjusted to achieve a suitable downstream effect.

An interesting result is that the lowest relative velocity occurs not at the retard but a short distance downstream of the retard (Figure 4). The retard creates a uniform velocity profile which initially results in much higher energy losses to bed friction and hence a decrease in velocity. Furthermore this zone, immediately downstream of the retard, is subject to high shear stress. Therefore some scour can be expected immediately downstream of the retard.

The results in Figure 4 are for the situation where the increase in the velocity of flow behind the retard is due to the mixing with the high velocity flow above the retard with minimal lateral mixing from the high velocity water flowing in the channel, hence the results in Figure 4 are not applicable to locations near the channel end of the retard. A better understanding of this can be obtained from Figure 1 which shows a plan view of relative velocity contours behind a 50% open retard.

The results presented in Figure 1 were obtained in a straight flume and are unlikely to be directly applicable to flow in bends. At present the area of influence of a retard on a bend is determined by the angle of attack (a line tangential to the inside bank of the stream, passing the tip of the retard and extended downstream to the outer bank. The area between this line and the retard is defined as protected). This is not considered to be a particularly accurate method although it is believed to be conservative and the designer may wish to determine the area of influence as a compromise between the angle of attack and the results in Figure 1.

6 RETARD ANGLE

There was a general belief amongst those who had experience with retards that retards streamed flow across the river to the opposite bank and that this was partially due to the angle of the retard. This was based on the observation of a wave angling downstream of the retard towards the opposite bank. Dye tests in the flume determined that this wave was a surface feature only and that there was no streaming of flow from a retard. It is important to recognise that surface features do not indicate the true characteristics of the flow.

A question of considerable interest to designing engineers is what affect does the angle of the retard have on the relative velocity? The laboratory experiments showed that the angle of the retard to the flow has a minimal effect on the relative velocity. Thus the angle of the retard is free to be adjusted by the designer.

When setting the angle of the retard it is necessary to consider the possibility of the retard collecting debris and the porosity being severely reduced. In this situation the retard will act as a groyne and the diversion of the flow will be considerable, greatly increasing the potential for scour. Thus the retard should not be angled to point into the flow.

The effect of the angle of the last two panels at the channel end of the retard was found to influence the location of the scour hole (this forms immediately downstream from the tip of the retard). Angling the last two bays of the retard at approximately 30° and 60° to the line of flow results in the scour hole being located further out in the main channel.

7 MULTIPLE RETARDS

The main effect of retards is to slow the flow by providing additional resistance. They influence the flow for a considerable distance downstream (see Section 0). As such it is possible that the flow approaching a retard may be influenced (ie. had its velocity reduced) by the retard(s) upstream of it. Hence with correct retard spacing, interaction between retards can result in a cumulative decrease in velocity. To obtain a large decrease in velocity the upstream retards should be closely spaced, with larger spacing downstream to maintain the velocity below the desired level (Figure 4 indicates how velocity increases downstream of a retard).

The majority of the laboratory modeling was carried out using a single retard. The applicability of these results to multiple retards was tested and it was found that the response of multiple retards could be determined by analysing each retard as a single retard subject to the flow conditions from the retard(s) upstream of it. Thus to determine the relative velocity behind a retard that is influenced by an upstream retard the following steps need to be applied.

1. For a given depth of flow and retard porosity determine the relative velocity behind the upstream retard (use Figure 2)
2. Based on the distance to the second retard, and the relative velocity behind the first retard determine the actual velocity in front of the second retard (use Figure 4). This is the control velocity for the second retard.
3. Based on the selected porosity of the second retard and the selected depth of flow determine the relative velocity applicable to this retard (use Figure 2).
4. The actual velocity behind the second retard is the product of the control velocity (from 2) and the relative velocity of the retard (from 3).

8 SEDIMENT MOVEMENT

Retards are used to form an artificial bankline and hence train the river to a different course. The expected life of a retard is 10 - 20 years and thus for a long term solution it is necessary to have sediment deposit in the embayments and form an artificial bankline. When considering sediment movement within an embayment there are two points to consider. The first is the retention of the original bed material. Once this is eroding the retard can be considered to have failed. The second point is the deposition and retention of fine sediment which is important for the establishment of vegetation.

There are four fundamental considerations to achieving stable sediment deposition. These are:

- risk management and the failure flood;
- velocity of flow;
- berms; and
- vegetation.

8.1 Risk Management and the Failure Flood

The successful implementation of retards is fundamentally a procedure in risk management. The first point to recognise is that it is uneconomic, if not impossible, to build a structure that can successfully protect the bank and deposit sediment in all possible flow conditions. However the retard design can be varied to adjust the risk of failure.

Failure is defined as the flow at which the bed material (as distinct from the deposited fines) within the embayments is eroded. By use of a flood frequency relationship and hydraulic consideration of the reach, the designer should be able to estimate the velocity and stage of flow associated with floods of different annual exceedence probability. From this and the velocity information in Section 8.2 the designer can determine what is the annual exceedence probability of the failure flood for a given design. It should be noted that the magnitude of the failure flood will increase as the vegetation becomes established and assists the retards in protecting the bed material from erosion. Hence the most critical period for failure of retards is the period from construction until the vegetation becomes established.

Considering the deposition of fines, if the embayments are higher than the low flow channel, then there will be a continuum of events that cause the embayments to become inundated. Directly related to this will be a range of velocities over the embayment; extending from near zero when the embayment is just inundated to the velocity associated with the failure flood. Linked to these velocities is a range of erosion and deposition outcomes. These will range from minor freshes that will barely cover the embayment and deposit very fine material, to moderate events that will erode fine material but deposit coarser material, to the failure flood that will erode all material sizes in the embayment, including the bed material.

The implication of this for designers is that by adjusting the berm height and the design of the retards the designer can influence the magnitude of the failure flood and the impact of the more frequent events. This is where the risk management concept comes in as the designer has to weigh up the cost of some additional works against the decrease in the risk in failure associated with the works.

8.2 Velocity of Flow

Research has shown that the erosion of a particle can be related to the mean stream velocity. Hence when designing retards it is possible to determine whether the flow velocity behind the retard will be sufficient to move particles, or whether they will remain stable. Table 1 relates the hydraulic radius, particle size (based on median sieve diameter), and velocity at which particles of that size begin to move. This table is based on the results of Yang (1973). These results can be used in conjunction with the estimated flow velocity, the relative velocities from Figure 2 and the downstream effects from Figure 4 to determine a suitable layout and porosity of the retards such that the desired sediment size will remain stable.

To assist with this analysis the designer should consider the particle size distribution of sediment carried by the river at that location. The simplest way to obtain this information is to carry out a basic sieve analysis of the bed material and material from a site where sediment has deposited. With the bed material the designer should consider the following points.

- Could the bed material form an armour layer. If so what size material would form this armour layer and is there enough of this material to form an armour layer quickly.
- What size material needs to be eroding such that the bed can be considered to be fully mobile and hence the retards have failed.

By considering these the designer should be able to obtain an estimate of the particle size that is considered representative of the bed material. The velocity associated with this can then be used to determine the failure flood magnitude and hence the annual exceedence probability of the failure flood.

The sieve analysis of the deposited material will give the designer some indication of the material that is being carried and hence what is available for deposition. Using this information and the velocities from Table 1 the designer can determine what proportion of this material will be trapped and held in a stable manner for a given design of the retards and a given flood magnitude. Alternatively the designer can use empirically derived sediment transport relationships to relate velocity to the size of sediment being transported. If necessary, the design can be adjusted to improve on this. Again the cost of the design will have to be considered against the amount of sediment that is expected to be trapped.

The velocities in Table 1 are for incipient motion (ie. the first particles beginning to move) and thus slightly higher velocities will cause some movement of the particles, but not sufficient to result in significant erosion. It is not known by how much the velocities in Table 1 can be exceeded before the erosion rate becomes significant.

8.3 Berms

A berm is a raised area on which retards are built. They are usually constructed to allow the retards to be built on dry land. Berms have several other advantages which are outlined below.

- The berm diverts the low flow channel away from the retards and the eroding bank, reducing erosion of deposited sediment.

Table 1 Critical velocities for different particle sizes and different hydraulic radii. Note that on a wide berm the hydraulic radius is approximately equal to the depth of flow.

Critical Velocity m/sec		**Hydraulic radius m**							
		0.1	0.15	0.2	0.25	0.30	0.35	0.40	0.45
Particle diameter mm	1	0.32	0.31	0.30	0.29	0.28	0.28	0.28	0.27
	2	0.46	0.44	0.43	0.42	0.41	0.41	0.41	0.41
	3	0.53	0.51	0.51	0.51	0.51	0.51	0.51	0.51
	4	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
	5	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
	6	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74
	7	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
	8	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
	9	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87
	10	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90

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- The berm provides a location, above water level, on which revegetation can commence.
- If the berm is uneven, then during the recession of an event sites where there is deeper water will have lower velocities, allowing finer sediment to deposit, which will in turn assist in the establishment of vegetation. This process can be assisted by deliberately creating gentle hollows in the berm (approximately 300 mm deep). It is important that these hollows be laid out such that they do not form a potential flow path.
- The elevation of the berm needs to be determined with respect to the flow regime of the river, the stage discharge relationship, and the vegetation to be planted. The lower the berm is, the longer and more frequently it will be inundated.

8.4 Vegetation

Vegetation has a major role in trapping and stabilising sediment in the embayments. Velocities for incipient motion (Table 1) are very low, and for fine particles, economically unachievable by the use of retards alone.

By combining vegetation with retards sediment trapping can be greatly enhanced. Vegetation has the following advantages.

- It increases the hydraulic roughness of the area between the retards and hence lowers the velocity. The velocities within dense vegetation (eg. grasses) can be very low, sufficient for the deposition and retention of very fine sediment.
- Careful choice of vegetation can give plants with an extensive root system which will mechanically bind particles, effectively creating a composite material of much greater strength.
- Grasses provide a surface cover to protect underlying soil.
- Fine material deposited on the recession limb of the hydrograph (when there are lower velocities) will, over time, be bound by the vegetation and stabilised against erosion in further events.
- In small events the vegetation will act like a sieve and trap floating debris. This in turn will provide humic matter for the vegetation.
- As vegetation becomes established it decreases the annual exceedence probability of the failure flood and thus decreases the risk of failure of the retards.

Key properties for vegetation for use with retards are:

- fibrous root systems;
- able to survive in poor soils (eg gravel from the river bed); and
- able to cope with periods of inundation.

The necessity of vegetation in the successful implementation of retards in a long term river training strategy can not be over emphasised. Field surveys indicated that the greatest deposition of material occurred where vegetation was successfully established. Several highly successful rehabilitation works have been based solely on the use of lines of willows (vegetative retards) although it should be noted that the use of vegetative retards is a higher risk option than the use of retards and vegetation.

9 CONCLUSION

This research has developed a series of analytical relationships which can be used in conjunction with the general guidelines for the design of retards. These have been combined in a report "Retards and Groynes: Design Guidelines" available from the Division of Catchment and Land Management, Department of Conservation and Natural Resources, Victoria.

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