CONCEPT NOTE: PERMISSIBLE VELOCITY IN CONCRETE LINED TUNNEL (HRT) CONVEYING WATER FOR POWER GENERATION

1.0 Introduction

In hydro-electric project, head race tunnels carry water from the intake to the turbines for power generation. After the final alignment of the tunnel (Water Conductor System) has been chosen by carrying out detailed planning and investigations, the next step for the designer is to choose a suitable geometric section of the tunnel by adopting an appropriate flow velocity. The flow velocity selection in Head Race Tunnel is generally governed by two contradictory economic aspects. On one hand going for larger tunnel cross section to keep flow velocity low and head loss minimum, increases cost of tunnel construction. On the other hand, designing tunnel cross section for economic diameter brings velocities on higher side thus increases head loss (resulting in recurrent power generation loss). The design of the hydraulic tunnels should be such that total friction losses in the tunnel must not be great enough to impair the output and regulation of the machines. Further sediment load carried by the water flowing in the tunnel and sediment characteristics also play important role in finalizing the section of the tunnel. As the water carrying suspended abrasive material (sediment with significant sand fraction) can cause abrasion in the lining and over the years can result in the deterioration of the concrete lining which may severely affect the performance of the tunnel and thus impact the power generation. This aspect needs to be given due weightage while adopting permissible velocity in the tunnel. Limited literature is available on the performance of the concrete lining in power tunnel post commissioning. But literature suggests certain limits on the flow velocity in the tunnels depending on the composition and amount of the sediment carried by water.

2.0 Current Provisions in Indian Standard

With regard to average permissible velocity in tunnel, **Indian Standard: 4880 (Part III) - 1976** recommends that-

Clause 5.1 *Average permissible velocity in a concrete lined tunnel may be about 6 m/s. For steel lined tunnels velocities as dictated by economic studies shall be chosen. In case of river diversion tunnels and tunnel spillways there may be no such limitations on the maximum permissible velocity, however, the lining and its surface shall be designed to withstand the velocities which will occur.*

Sub clause 5.1.1 *Permissible velocities in tunnels of different surfaces (unlined, concrete lined, steel lined) also depend upon the sediment load carried by the water. Where water carrying abrasive material in suspension and as bed load is to be conveyed the permissible velocity should be reduced. A recommended velocity is 2.5 m/s.*

Above guidelines do not clarify certain terms and leave scope for subjective interpretation and execution-

1- Explicit meaning of term *"abrasive material"* is not mentioned.
2- Clear inference of economic studies viz a viz abrasion of lining is not indicated.
3- The codal provisions do not provide exact value of average permissible velocity for different characteristics of flowing water such as- presence of sharp edged sand, silt, clay & their specific quantities; *duration of exposure* to heavy sediment load at higher velocity.

3.0 Literature Review

A literature review was undertaken on the issue. The provisions as proposed in different manuals/guidelines are below:

A. Mosonyi Vol-IIA, 1991 suggests that "to reduce the construction costs, relatively high velocities should be permitted in tunnels, higher ones than those allowed in open canals. *Permissible velocity depends upon the sediment load carried by the water.* Further it is suggested in the book that *tunnels should be protected by a carefully placed concrete lining highly resistant to wear*. Bearing in mind that excessive velocities increase the head loss and are thus uneconomical, following limit velocities are proposed for specific conditions of lining-

Table -1

Sl No.	Characteristics	Value of velocity (m/sec)
1	Concrete lining with water carrying *sediment not greater than silt fraction*	2-4
2	Concrete lining with water carrying *sharp edged sand in significant quantities*	Not to exceed 2-2.5
3	Clear water and exceptionally large cross section (to reduce construction cost)	5
4	Steel lining	2.5 to 7

B. U.S. Army Corps of Engineers, EM 1110-2-2901, 30 May 97, *the allowable velocities in different kinds of water tunnels are restricted by potential cavitation damage depending on the lining material used sediment deposit and flushing characteristics*. The manual makes following recommendations on similar lines-

Table -2

Sl No.	Characteristics	velocity (m/sec)
1	Tunnel with no lining	Less than 3
2	*Concrete lining*	3-6
3	*Concrete lining Water carrying silt, sand and gravel*	Less than 3
4	Steel or special inner lining	More than 6

C. CBIP publication on 178 "Manual on the Planning and design of hydraulic tunnels" provides following recommendation:

Permissible velocity in a concrete lined tunnel is of the order of 6 m/s. Higher velocities are allowed in steel lined tunnels.....*The maximum permissible velocity shall be limited*

to approximately 3m/s in the case of tunnels conveying suspended abrasive materials.

D. Hydroelectric Engineering Practice, Vol. 1, JG Brown (1958) referred by IS code 4880 Part III provides following recommendation:

The maximum permissible tunnel velocity is usually from 10 to 12 ft/Sec. (about 3-4 m/s) in main pressure tunnels. Greater velocities will increase the risk of erosion of the concrete lining and may case vibrations in gates and pipelines. ..... After some years of service, deterioration of the lining will probably increase its roughness and reduce the capacity of the tunnel. To meet this risk, the tunnel dimensions should be somewhat greater than those determined solely from theoretical requirements.

E. International Journal of Civil and Environmental Engineering Vol-10, No.-6, 2016 on "Practice in Planning, Design and Construction of Head race Tunnel of a Hydroelectric Project" by MS Thakur and Mohit Shukla also points out that average permissible velocity in a concrete lined tunnel may lie between 4 and 5 m/sec and depending on the nature of sediment load the velocity may be varied accordingly.

F. IS: 4880, Part -VII (2014) has reduced velocities in Steel lined tunnels to 7 m/s (maximum) from the earlier provision of 9 m/s in first revision of the code.

G. A review of "**Directory of Tunnels**" publication number 306 (CBIP), suggests that head race tunnels in Himalayan region have been designed (planned or operational) for velocities ranging from 3m to 6m/s with large no. of tunnels designed between 4-5 m/s of velocity.

It has been observed that velocities in the HRT are generally kept from the considerations of the economical diameters and geology

but due weightage to the presence of the sediment contents and their characteristics are not been given while allowing the velocity in the head race tunnels. In light of above precedents being followed domestically and abroad, provisions with regard to permissible velocity in lined tunnels conveying water, may be considered for revision. *Codal provisions may need revision so as to suggest explicit permissible value of average velocity with respect to different characteristics of flowing water- sharp edged sand, silt and gravel etc. This standardization may help in bringing more uniformity in design practice and greater convergence of velocity values being adopted for the same.* Further there is a need to be careful while technical examination of hydropower projects in CWC.

Recommendations:

Based on literature review, it is proposed that the provisions of permissible velocity in **Clause 5.1 and Sub Clause 5.1.1 of IS:4880, Part-III** needs to be rationalised as follows to bring down gaps in them-

(i) Presently desilting chambers are provided in the water conductor system with efficiency of about 90% to remove sediment of particle size greater than 0.2 mm for high head Hydro-electric Projects. However sand particles of size 0.075 mm to 0.2 mm may still remain in the water flowing in the Head Race Tunnel (HRT). So for all Run of the River schemes, where the sediment removal is a prerequisite and the concrete lined tunnels carries water containing **significant** (>400 ppm) sand fraction (0.075mm & above) sediment (i.e. *sharp edged sand in significant quantities*) load, the maximum permissible velocity in HRT shall be **restricted to 3 m/s**.

(ii) In flow containing sediment having a total sand fraction less than 400 ppm (out of which the concentration of sand fraction of size 0.2 mm and above not to exceed 75 ppm); and Slit & clay fraction particles concentration may range between 0-4000 ppm, maximum permissible velocity in concrete lined tunnels shall be **restricted between 3-4 m/s.**

(iii) In flow containing sediment having a total sand fraction concentration less than 250 ppm (having sand particle size less than 0.2 mm); and slit & clay fraction particles concentration ranging between 0-4000 ppm, the maximum permissible velocity in HRT shall be **restricted between 4-5m/s**.

(iv) In flow having negligible sediment (less than 250 ppm total), the maximum permissible velocity in HRT shall be **restricted between 5 – 6.** (With max velocity of 6 m/s limited for short duration).

(v) Tunnels carrying significant sand fraction of sediment shall be provided with lining of high strength mix.

(vi) More data needs to be collected from existing HEP's regarding variation of head loss in HRT over the years viz-a-viz the discharge/velocities and sediment in it.

(vii) The velocity in HRT needs to be correlated to material of lining, sediment concentration, particle size distribution/proportion of abrasive materials in it.

(viii) Codal provisions may need revision/review so as to suggest explicit permissible value of average velocity with respect to different characteristics of flowing water- sharp edged sand, silt and gravel etc, and material of lining.

(ix) As a first step, the provisions of permissible velocities in HRT as given in BIS code can be elaborated as shown in **Table 3** below. This standardization may help in bringing more uniformity in design practice and greater convergence of velocity values being adopted for the same.

Table 3

Category	**Characteristic of tunnel flow**	**Maximum Permissible Velocity (M/s)**
1.	Flow containing significant (>400 ppm) fraction of sand particles (0.075 mm & above) in the sediment carried by it.	<3
2.	Flow containing sediment having – a. A total sand fraction less than 400 ppm (out of which	3-4

	the concentration of sand fraction of size 0.2 mm and above not to exceed 75 ppm); and b. Slit & clay fraction particles concentration may range between 0-4000 ppm.	
3.	Flow containing sediment having- a. A total sand fraction concentration less than 250 ppm (having sand particle size less than 0.2mm; and b. Slit & clay fraction particles concentration may range between 0-4000 ppm.	4-5
4.	Flow having negligible sediment (less than 250 ppm total)	5 – 6 (see note 2) (Max velocity of 6 m/s shall be limited for short duration)

Note:

1. Tunnels carrying category-1 flow shall be provided with lining made up of high performance concrete.
2. For flow touching 6 m/s velocity, the duration of exposure may be limited to 30 minutes/day and 90 hours/year.

(x) Once a broad consensus on proposed changes is achieved, the same can be sent to BIS for processing in suitable Sectional Committee on Water Conductor Systems (WRD-14) where more inputs from other stakeholders may also come. However, since these proposed changes/modifications are minor and are intended to make the IS code provisions explicit and in turn more objective, CWC may start recommending the modified provisions in all the new projects, whose design is yet to be finalized as this aspect or the projects under technical examination.

***