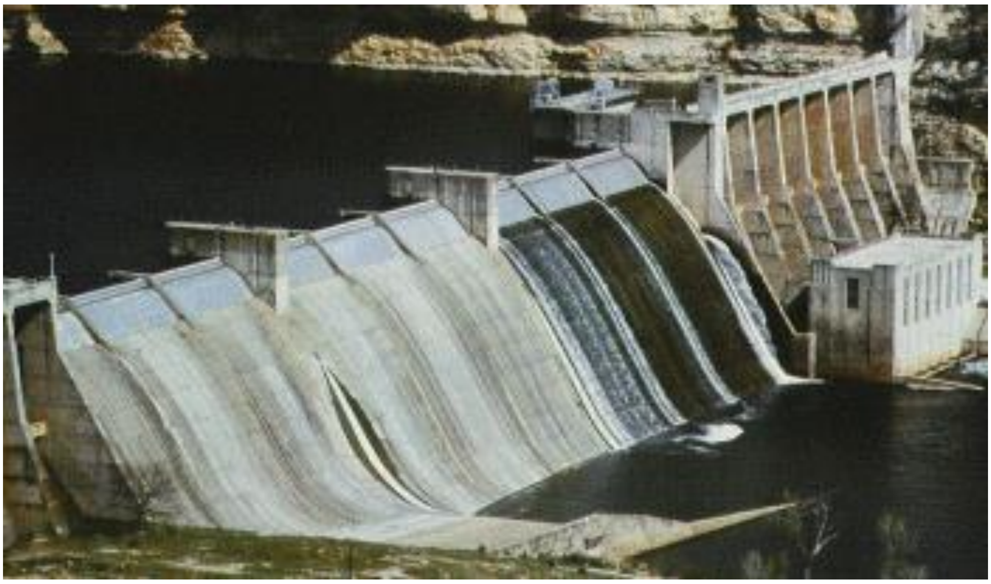
Overflow Spillway



A spillway acts as a safety valve on a dam. Spillways are designed to pass large amount of water safely over the crest of the dam during storms. ***The provision (البند الخاص) of adequate spillway facilities can pose (يشكل) more problems than the design of the dam.*** The existing or possible future habitation in the valley below the dam must influence decisions to be made regarding the spillway.

For small dams, their design shape is not that critical. On large dams, their effectiveness is highly dependent on shape.

Hydraulic aspects of spillway design extend to the design of the three spillway components: ***control structure, discharge channel, and terminal structure***. The ***control structure*** regulates outflows from the reservoir. Design problems relate to determining the shape of the section and computing discharge through the section. The flow released through the control structure is conveyed to the streambed below the dam in a ***discharge channel***. An estimate of the loss of energy through the channel section is important in designing the ***terminal structure***. Terminal structures are energy-dissipating devices that are provided to return the flow to the river without ***serious scour or erosion at the toe of the dam***. These comprise a hydraulic jump basin, a roller bucket, a sill block apron, or a basin with impact baffles and walls. Spillways are usually referred to as controlled or uncontrolled, depending on whether or not they are equipped with gates.

Conclusion:

Uses (function):

-the safety valve for a dam

-discharges major floods & keeps reservoir below predetermined level

1. Controlled (crest gates)
2. Uncontrolled

Required Capacity (Maximum Outflow Rate through the spillway)

1. Spillway design flood (inflow hydrograph to reservoir)
2. Discharge capacity of the outlet works
3. Available storage

*All depend on type of dam, location, & consequences of failure

For controlled spillway:

- Gates may be positioned on the crest for “overflow regulation”.
- During the floods, if the reservoir is full, the gates are completely open to promote the overflow.
- A large number of reservoirs ***with a relatively small design discharges are ungated***.

- Currently most large dams are equipped with gates to allow for a flexible operation.
- The cost of the gates increases mainly the magnitude of the flood, i.e.: with the overflow area.
- ***Improper operation and malfunction*** of the gates is the major concern which may lead to serious overtopping of the dam.
- In order to inhibit floods in the tail water, gates are too moved according to gate regulation.
- Gates should be checked against vibrations.

The Advantages and Disadvantages of Gates:

The advantages of gates at overflow structure are:

- Variation of reservoir level,
- Flood control,
- Benefit from higher storage level.

The disadvantages are:

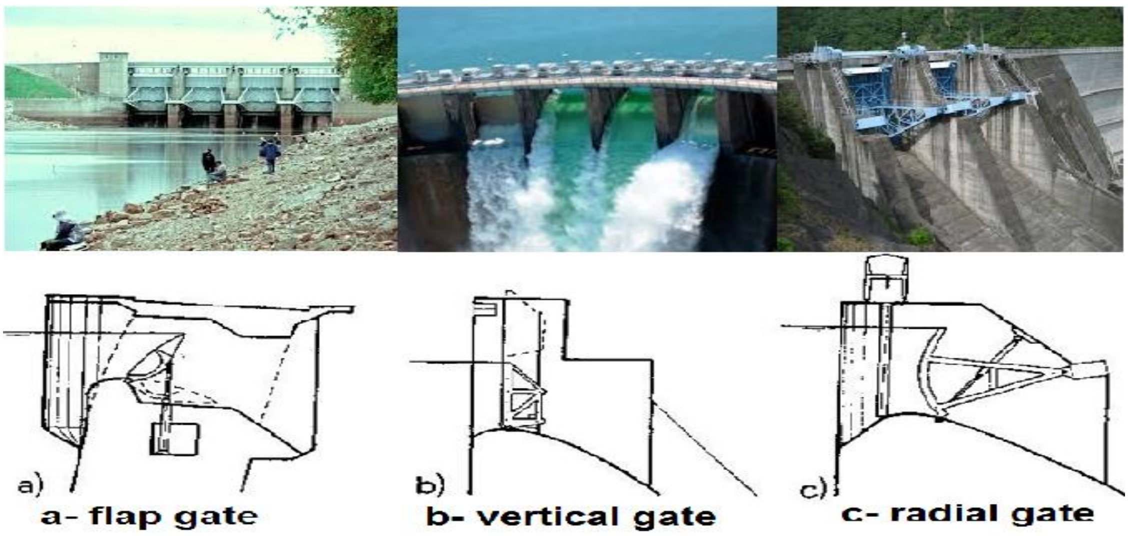
- Potential danger of malfunction,
- Additional cost and maintenance.

Depending on the size of the dam and its location, one would prefer the gates for:

- Large dams,
- Large floods, and
- Easy access for gate operation.

Three types of gates are currently favored:

- Hinged flap gates,
- Vertical lift gates,
- Radial gates.



Three Types of gates

- The flaps are used for a ***small head of some meters***, and may span over a ***considerable length***.
- The vertical gate can be ***very high but requires substantial slots, a heavy lifting device, and unappealing superstructure.***
- The radial gates are most frequently used ***for medium or large overflow structures*** because of their ***simple construction, the modest force required for operation and absence of gate slots***.

For all three types of gates

- The risk of gate jamming in seismic sites is relatively small, if setting the gate inside a stiff one-piece frame.

- For safety reasons, there should be a number of moderately sized gates rather than a few large gates.
- For the overflow design, it is customary to assume that the largest gate is out of operation.
- The regulation is ensured by hoist or by hydraulic jacks driven by electric motors.
- Stand-by diesel-electric generators should be provided if power failures are likely.

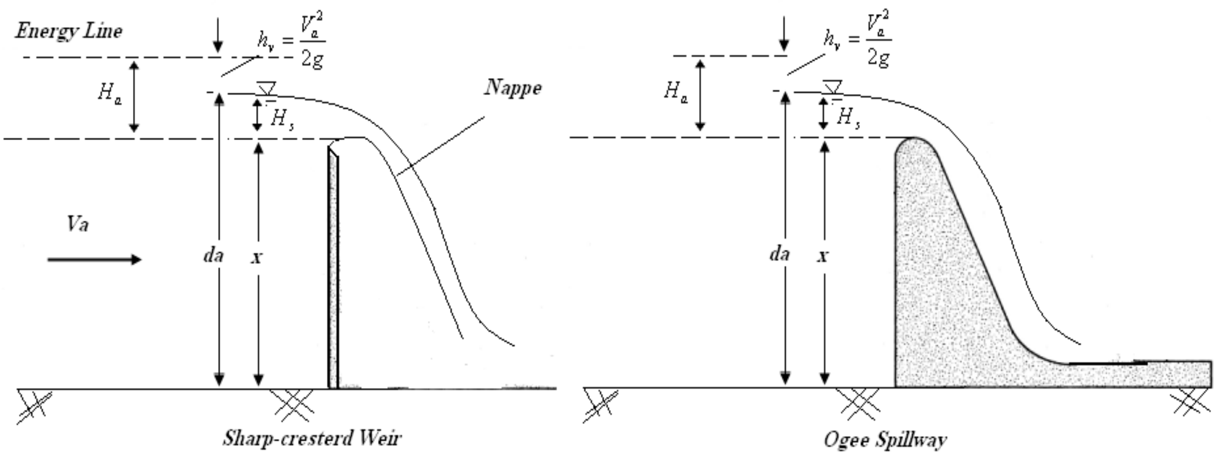
Types of Spillways:

1. Ogee Spillway,
2. Side Channel Spillway,
3. Chute Spillway,
4. Shaft Spillway,
5. Siphon Spillway.
6. Service & Emergency spillways.

Ogee Spillway

It is widely used on gravity and buttress dams (large or high dams). ***The ideal longitudinal profile of ogee spillway should flow along the same curve as the underside of the free falling water nappe to minimize the pressure on the spillway surface.***

- ***Caution must be exercised to avoid any negative pressure on the surface,***
- ***Negative pressure is caused by separation of the high-speed flow from the spillway surface, resulting in a pounding action that can cause significant damage to the spillway structure (e.g., pitting resulting from cavitation plus the vibration).***



Cavitation effect on the spillway crest

Design of Ogee Spillway

The design procedure is depends on:

1-Discharge of Spillway:

The discharge of a spillway calculated from the following equation

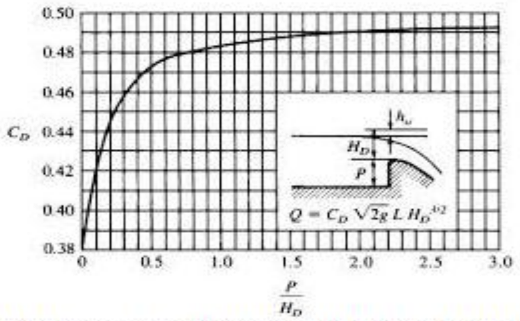
$$Q = C\sqrt{2g}LH^{3/2}$$

Where;

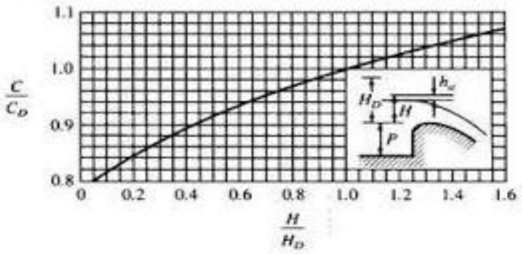
Q=discharge, C=the coefficient of discharge, L=is the width of the spillway crest, H=the sum of static (design) head (Hd or Hs) and approaching velocity head (ha) at the crest.

$$H = H_d + \frac{V_a^2}{2g}$$

- The coefficient C depends on the approach depth, actual shape of the crest, and upstream face slope.



a-Discharge coefficient vs P/Hd for design head



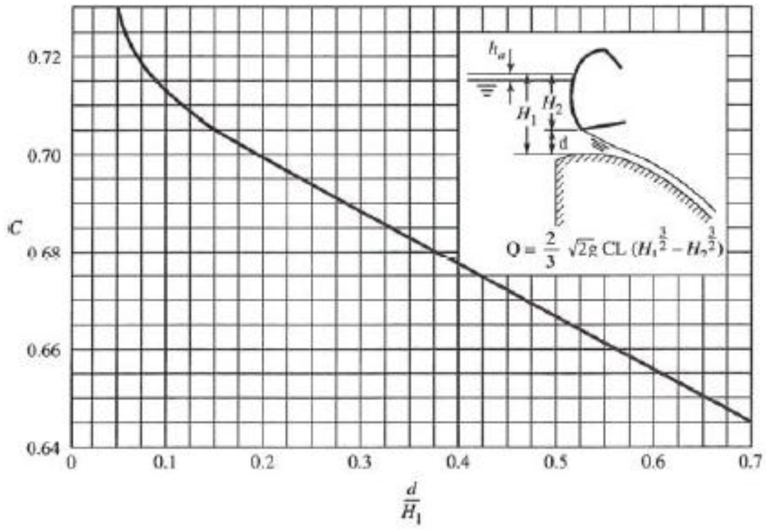
b- C/Cd vs H/Hd

Design Chart 1.Coefficient of discharge for ogee crests with vertical faces (Roberson, Cassidy, Chaudhry, 1998)

- Overflow spillways frequently use undershot radial gates for releases over the dam. The governing equation for gated flows,

$$Q = \frac{2}{3}\sqrt{2g}CL(H_1^{3/2} - H_2^{3/2})$$

Where C is a coefficient of discharge, and H_1 and H_2 are total heads to the bottom and top of the gate opening. The coefficient C is a function of geometry and the ratio d/H_1, where d is the gate aperture. ***Piers*** placed on spillways to furnish structural support for the gates not only *reduce effective flow-passing length of the spillway crest* by the width of the piers but also cause *flow contractions* that further *reduce the effective length*, particularly if the nose of the pier is *not rounded*.



Design Chart 2.Coefficient of discharge for flow under gates (USBR, 1988)

Overflow spillways are named as *high-overflow*, and *low-overflow* depending upon to the relative upstream depth P/H_D. In high-overflow spillways, this ratio is (**P/H_D>1.33**) and the approach velocity is generally ***negligible***. *Low spillways have appreciable approach velocity*, which affects both the shape of *the crest and the discharge coefficients*. (**Ref. A.Bulu**)

2-Crest Shape of Overflow Spillways

The lower surface of a nape from a sharp-crested weir is a function of,
1. The head on the weir,
2. The slope or inclination of the weir surface,
3. The height of the crest, which influences approach velocity.

On the crest shape based on a design head H_D, when the actual head is less than H_D, the trajectory of the nape falls below the crest profile, creating positive pressures on the crest, thereby reducing the discharge. On the other hand, with a higher than design head, the nape-trajectory is higher than crest, which creates negative pressure pockets and results in increased discharge. *Accordingly, it is considered desirable to under-design the crest shape of a high overflow spillway for a design head H_D, less than the head on the crest corresponding to the maximum reservoir level, H*. However, with too much negative pressure, cavitation may occur. The U.S. Bureau of Reclamation (1988) ***recommendation has been that H/H_D should not exceed 1.33***. The Corps of Engineers (COE) has accordingly recommended that a spillway crest be designed so that the maximum expected head will result in an average pressure on the crest no ***lower than (-4.50m)*** of water head (U.S. Department of Army, 1986). Pressures of (-4.50m) can be approximated by the following equations (Reese and Maynord, 1987).

For H, $H_D \geq$ 10 m,

$H_D = 0.43H^{1.22}$ (Without piers)

$H_D = 0.39H^{1.22}$ (With piers)

For H, $H_D <$ 10 m,

$H_D = 0.7H$ (Without piers)

$H_D = 0.74H$ (With piers)

Another empirical equation given for the maximum head on the crest for no cavitation is,

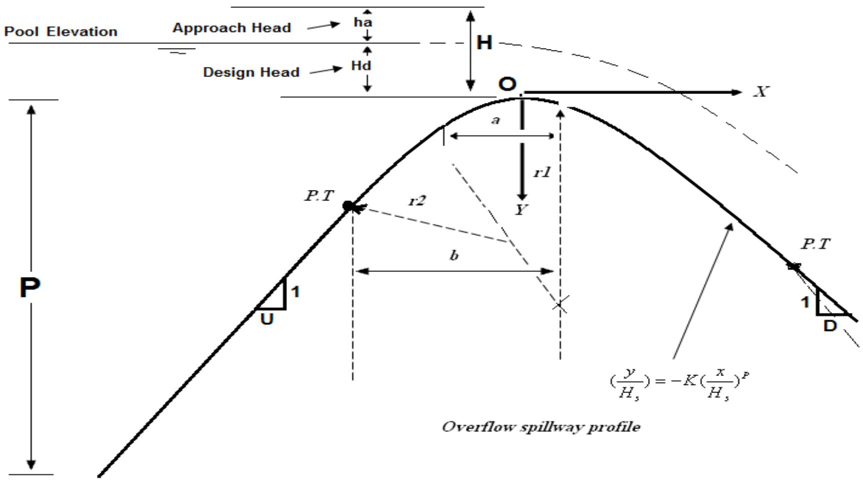
$H_{max} = 1.65H_D$

The U.S. Bureau of Reclamation described the complete shape of the lower nappe by separating it into two quadrants, one upstream and one downstream from the crest (apex), as shown in Figs (below). There are two methods to determine the profile downstream from the crest of spillway:

1. By design table

The profile downstream from the crest can be determine from the following equation

$$\left(\frac{y}{H_s}\right) = -K\left(\frac{x}{H_s}\right)^P$$



Definition sketch (design table method)

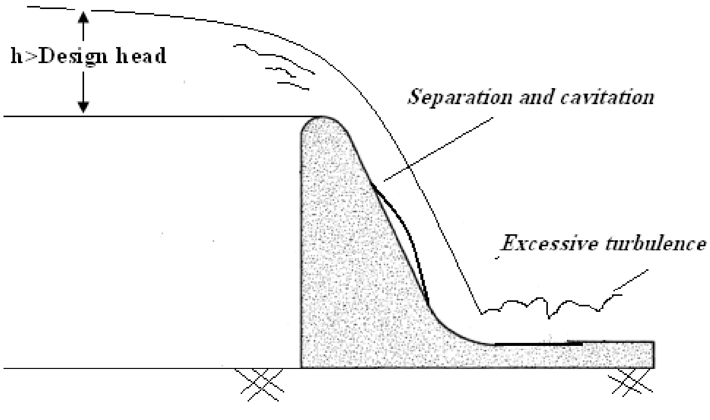
Hs(HD) = Design head excluding the velocity approach head.
x, y = Coordinates of the crest profile, with the origin at the highest point (O), as shown in Fig.
K, P = Constants that depend on upstream inclination and approach velocity.
The following table can use for design purpose:

Design table: Upstream slope (ver/hor.)

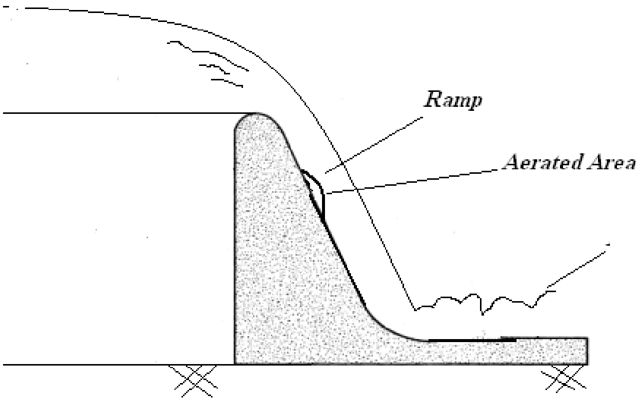
	3/0	3/1	3/2	3/3
a/Hs	0.175	0.139	0.115	0
b/Hs	0.282	0.237	0.214	0.199
r1/Hs	0.5	0.68	0.48	0.45
r2/Hs	0.2	0.21	0.22	-
K	0.5	0.516	0.515	0.534
P	1.85	1.836	1.81	1.776

Not:

In some cases may be the flow exceeds design capacity of spillway therefore following treatments can be used,



Ogee spillway when flow exceeds design capacity



Ogee spillway with ramp to provide protection from cavitation

Example (1): An overflow spillway (type ogee) 80m wide carries a maximum discharge of 400m^3/s. Define the crest profile for the spillway. Consider the upstream slope is (V: H) is (3:1) and downstream slope (V: H) is (2:1) assume C=2.2?

Sol:

Assume a minimum approach velocity hv=0   Ha=Hs

$$Q = 2.22LH_s^{3/2} \Rightarrow H_s = \left(\frac{Q}{2.22L}\right)^{2/3} \Rightarrow \left(\frac{400}{2.22*80}\right)^{2/3} = 1.72m$$

From the table, we have

$$a = 0.139H_s = 0.239m; \Rightarrow r_1 = 0.68H_s = 1.17m$$

$$b = 0.237H_s = 0.408m; \Rightarrow r_2 = 0.21H_s = 0.361m$$

$$K = 0.516; \Rightarrow P = 1.836$$

And

$$\left(\frac{y}{H_s}\right) = -K\left(\frac{x}{H_s}\right)^P = -0.516\left(\frac{x}{H_s}\right)^{1.836}$$

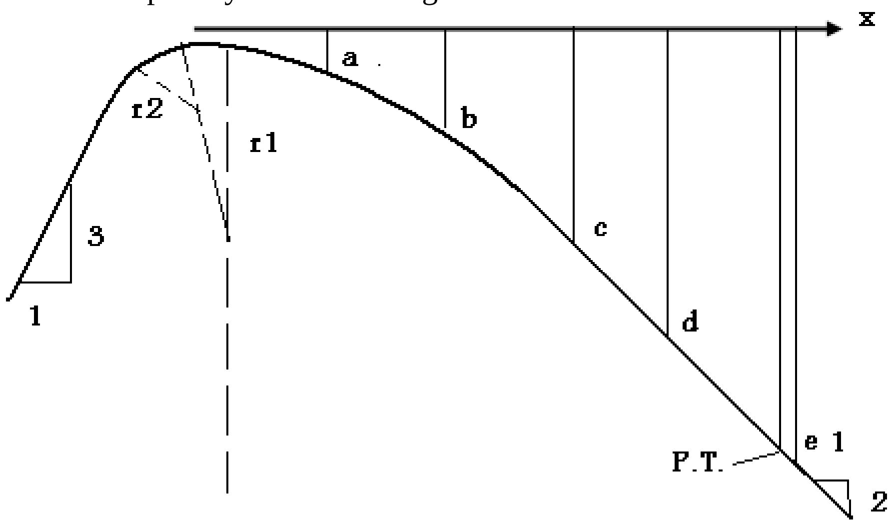
The downstream of the profile curve will be matched to a straight line with slope 2:1. The position of the point of tangency is determined by

$$\frac{d\left(\frac{y}{H_s}\right)}{d\left(\frac{x}{H_s}\right)} = -KP\left(\frac{x}{H_s}\right)^{P-1} = -0.947\left(\frac{x}{H_s}\right)^{0.836} = -2$$

$$\frac{X}{H_s} = 2.45, \Rightarrow X_{P.T.} = 4.21m$$

$$\frac{Y}{H_s} = 2.674, \Rightarrow Y_{P.T.} = -4.599m$$

The crest profile curve of the spillway is shown in fig. below:



Point	x/Hs	x	y/Hs	y
a	0.5	0.86	-0.145	-0.249
b	1	1.72	-0.516	-0.888
c	1.5	2.58	-1.086	-1.868
d	2	3.44	-1.842	-3.168

e	2.5	4.3	-2.775	-4.773

Example (2): Design an overflow spillway section for a design discharge of 1500 m^3/sec. The upstream water surface level is at elevation 240 m and the upstream channel floor is at 200 m. The spillway, having a vertical face, is 50 m long.

Sol:

1. Assuming a high overflow spillway section, for $P/H_D \geq 3$, discharge coefficient $C_D = 0.49$ from design chart 1.
2. From the discharge equation:

$$Q = C\sqrt{2g}LH^{3/2}$$

$$H^{3/2} = \frac{Q}{C\sqrt{2g}L} = \frac{1500}{0.49\sqrt{19.62}*50} = 13.822$$

H=5.76m

3. Depth of water upstream=240-200=40m

   Velocity of approach= $V_0 = \frac{1500}{40*50} = 0.75 m/s$

   Velocity head= $\frac{V_0^2}{2g} = \frac{0.75^2}{19.62} = 0.03m$
4. Maximum water head = $5.76 - 0.03 = 5.73m$
5. Height of the crest = $40.00 - 5.73 = 34.27m$
6. Since H= 5.76m < 10m

   Design head = HD = 0.7H =0.7*5.76=4.03m
7. $\frac{P}{H_D} = \frac{34.27}{4.03} = 8.5 \rangle 1.33$ high overflow
8. Downstream quadrant from Eq.

   $(\frac{y}{H_D}) = \frac{1}{K}(\frac{x}{H_D})^{1.85}$ From design chart (3), P/H_D =8.5, K=2

   $(\frac{y}{4.3}) = \frac{1}{2}(\frac{x}{4.3})^{1.85} \Rightarrow y = 0.15x^{1.85}$

Coordinates of the shape computed by this equation as follows:

x (select) (m)	y (computed) (m)
1	0.15
2	0.54
3	1.14
4	1.95
5	2.95
6	4.13
7	5.49
8	7.03
9	8.74
10	10.62